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PARTMENT OF AGRICULTURE,
WEATHER BUREAU.

BULLETIN No. 3.

A REPORT

ON THE

RELATIONS OF SOIL TO CLIMATE.

BY

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,

Washington, D. C., July 15, 1892.

SIR: I have the honor to transmit herewith a report on the Relations of Soil to Climate, by Prof. E. W. Hilgard, of the University of California, and to recommend its publication as Weather Bureau Bulletin No. 3.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

Hon. J. M. RUSK,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

UNIVERSITY OF CALIFORNIA,
COLLEGE OF AGRICULTURE,
Berkeley, Cal., May 31, 1892.

SIR: I have the honor to submit herewith for publication a report
on the Relations of Soil to Climate.

Very respectfully,

E. W. HILGARD.

MARK W. HARRINGTON,
Chief of Weather Bureau.

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THE RELATIONS OF SOIL TO CLIMATE.

Since soils are the residual product of the action of meteorological agencies upon rocks, it is obvious that there must exist a more or less intimate relation between the soils of a region and the climatic conditions that prevail, or have prevailed therein. It is the object of this paper to discuss, both from the theoretical and practical standpoint, some of the more important phenomena dependent upon this correlation, and their effects upon the agricultural peculiarities of the chief climatic subdivisions.

In order to render this discussion intelligible to the general reader it will be best to summarize, as briefly as may be, the several agencies that contribute toward the process of soil formation from rocks and their decomposition products.

THE PROCESSES OF SOIL FORMATION.

HOW SOILS ARE FORMED.

a. MECHANICAL AGENCIES.—The chief *mechanical* agencies concerned are the following, mentioned in the order in which they usually follow one another in nature :

1. Effects of *changes of temperature*, whereby the several minerals of which many rocks are composed are differently affected, so that their close adhesion is gradually weakened, and minute cracks are formed which give access to water and air, and to the small rootlets of plants.

2. Effects of *freezing water*, which widen still farther the minute crevices by its irresistible expansion, and in the case of the larger cracks rend rock masses into fragments, thus increasing the surfaces exposed and facilitating the removal of the rock from its original site, whether by gravity, moving water, or wind.

3. Effects of *moving or flowing ice* (glaciers). While at present confined to relatively limited areas, yet the powerful action of glaciers in grinding rocks to fine powder, from which soils form with great rapidity, renders this agency of great importance even at the present time; while in the past the enormous areas known to have been glaciated are covered largely with soils produced by this process conjointly with that of the water resulting from the melting of the ice. The rocks carried on the surface of glaciers are subject in the highest degree to the effects of changes of temperature, becoming intensely heated during clear days by the sun's rays when unaffected by the denser portions of the atmosphere, and at night again subjected to frost. These fre-

quent and violent changes assist greatly the merely mechanical grinding and abrading process resulting from the ice movement, both on the surface, within the ice mass (in the "crevasses"), and on the lower surface, which in the course of time becomes lined with stones that score the rocky bed with deep furrows. Hence glacier streams are always notable for the large proportion of very fine rock powder carried by them.

4. The effects of *flowing water* are doubtless at this time the most potent agencies of soil formation. Apart from the mere removal of loose materials from one point to another, its effects in carrying sand, gravel, and bowlders, according to velocity and volume, are prodigious. For these rock fragments not only score the bed of the stream or rill, but by their mutual attrition and abrasion produce more or less of fine powder similar to that produced by glacial action, but usually much more mixed in its ingredients, because derived from a wider range of surface. "Alluvial" soils thus formed are usually the most generalized in composition, while the "colluvial" soils of rolling uplands and slopes generally, are commonly, like those derived from glaciers, more of a localized character.

b. CHEMICAL AGENCIES.—The *chemical processes* that contribute essentially to the formation of soils are these:

1. *Solution by water alone*.—Since few substances known, and especially few of those forming rocks, are entirely insoluble even in pure water, while some (like gypsum) are easily dissolved in the latter, even rain-water carries these effects with it wherever it falls. But practically no pure water is found in nature, and it has required the utmost refinements of apparatus and manipulation to obtain it even artificially. The impurity which it almost invariably carries is an apparently weak, but in its ultimate effects very powerful, agent, viz.:

2. *Carbonic acid*.—The acid of "soda water," produced naturally by all processes of decay, fermentation, and slow or rapid combustion of vegetable and animal substances, coal, etc., as well as by the breathing of animals. Being contained in the air, this acid gas is absorbed in rain water and imparts to it additional solvent properties; being continually generated in the soil by the decay of the vegetable matter, it renders the soil water a relatively strong, acid solvent, which acts steadily upon the mineral matters of the soil and decomposes them still further, rendering their ingredients available for the nutrition of plants.

3. The *oxygen of the atmosphere* is active not only as taking part in the formation of carbonic acid, but also directly, in its action upon certain ingredients of rock minerals, notably the iron compounds. Most green and black minerals contain iron in a form (protoxide) which is capable of taking up more oxygen when opportunity is afforded. This occurs when carbonic acid water acts on the minerals containing the iron; the latter is then often completely eliminated in the form of

"rust" (ferric hydrate), causing the minerals and rocks to change their color from green or black to yellow or reddish, and by the increase of bulk softening or pulverizing the rock; while at the same time the carbonic acid dissolves and carries off, in water solution, a large proportion of the other ingredients.

4. In some cases, *water* enters directly into combination with the substances present or newly formed; thus increasing the bulk of the mass and forcibly rending the original structure. This happens in the formation of clay from feldspars, of gypsum from the mineral anhydrite, in the changing of black "ferrous" minerals into rusty brown, and in numerous other cases.

WEATHERING AND FALLOWING.—Thus the combined chemical action of water, carbonic acid, and oxygen, facilitated by the mechanical pulverization of the rocks, is most potent and constantly active in disintegrating both rocks and soils. Aside from the purely mechanical action of flowing water and ice, the effects of all the above agencies are comprehended under the term "weathering," and in agricultural practice, "fallowing."

CLASSIFICATION OF SOILS.

According to the predominance of the several agencies enumerated, the soils resulting from their action may be classified into three chief divisions, viz.: :

1. **SEDENTARY OR RESIDUAL SOILS**, or soils in place, which result from the quiet action of changes of temperature, frost, etc., in pulverizing the parent rock, together with the solvent action of water charged with carbonic acid and oxygen, but without any removal from the site of the original rock.

2. **TRANSPORTED SOILS**, which have been more or less removed from their original source, prevalently by the action of water, but also by the aid of gravity and winds. They naturally subdivide into two primarily important and universally recognized subdivisions, viz.: :

a. *Colluvial soils*, consisting of materials that have been transported short distances only and have not undergone any sedimentation or stratification in flowing water of watercourses, and the distribution of which bears no obvious relation to the latter. They may therefore contain débris of all sizes more or less uniformly distributed through their mass; and they form the bulk of upland and slope soils. In the regions covered by glacial drift, their materials may have come from great distances; but still the soil mass is destitute of any definite structure, such as belongs to—

b. *Alluvial or sediment soils*, which have been deposited in and from flowing water, therefore occupy areas distinctly related to present or former watercourses or lakes, and have a more or less distinct stratified or bedded structure, according to the nature of the depositing current or basin. The alluvial class therefore includes all "bottom" and

"second bottom" valley soils, as well as those of ancient or modern lakes and swamps.

It is hardly necessary to say that between these several classes of soils there is every degree of transition, and that it is frequently a matter of choice whether a given soil shall be considered as belonging to one or the other class. This is especially true of the older alluvial soils, many of which in the course of time have virtually become upland soils by the subsidence of the water or the rising of the land and its consequent erosion into hills. The great plains of the West, and many of the "mesa" lands of the continental interior and Pacific coast of America, are instances in point, and so are the ancient river terraces now lying high above the present flood-plains.

PHYSICAL NATURE OF SOILS.

Speaking in the most general terms, all soils may be considered as consisting of more or less finely powdered and decomposed *rock* (sand, silt), *clay*, and *vegetable matter* changed to greater or less extent toward the condition of humus or vegetable mold. The relative proportions of these three principal physical constituents determine the most general classification of soils according to their nature; as *sandy* or *light*, *clayey* or *heavy*, and *humus*. Beyond these, the degree of fineness of the rock débris and their chemical and physical constitution determines distinctions such as gravelly, sandy, silty, loamy, calcareous, siliceous, magnesian, ferruginous, and others of less general application although locally often of considerable importance.

CLIMATIC FACTORS THAT MODIFY SOILS.

INFLUENCE OF TEMPERATURE ON SOIL FORMATION.

Within the ordinary limits of atmospheric temperatures, all the chemical processes active in soil formation are intensified by high and retarded by low temperatures, all other conditions being equal. We can artificially imitate and produce in a short time, by the application of high temperatures, most of the chemical changes that naturally occur in soil formation.

This being true we should expect that the soils of tropical regions should, broadly speaking, be more highly decomposed than those of the temperate and frigid zones. While this fact has not been actually verified by the direct comparative chemical examination of corresponding soils from the several regions, owing to the want of uniformity in methods and the fewness of such investigations in tropical countries, yet the incomparable luxuriance of the natural as well as artificial vegetation in the tropics, and the long duration of productiveness*

*A special case in point is that of the fertile tract of volcanic soils extending between the cities of Guatemala and Antigua, that have been cultivated from the earliest times of settlement. When fresh these lands yielded about 75 bushels of maize. They have now fallen off to 15 to 20 bushels, but it has taken centuries to bring about this change.

that favors so greatly the proverbial easy-going ways and slothfulness of the population of tropical countries, offers at least presumptive evidence of the practical correctness of this induction. In other words, the fallowing action, which in temperate regions takes place with comparative slowness, necessitating the early use of fertilizers on an extensive scale, has been much more rapid and effective in the hot climates of the equatorial belt, thus rendering available so large a proportion of the soil's intrinsic stores of plant food that the need of artificial fertilization is there restricted to those soils of which the parent rocks were exceptionally deficient in the mineral ingredients of special importance to plants, that ordinarily form the essential material of fertilizers. Quartzose, magnesian, and other soils resulting from the decomposition of "simple" rocks will everywhere be poor in plant food; again, the intense decomposing or fallowing effect of tropical climates may be offset by an equally intense leaching process in consequence of copious rainfall. An example of this apparently occurs in the Hawaiian Islands, in the highly ferruginous soils resulting from the decomposition of the black (hornblendic) lavas that are so characteristic of the volcanic effusions of that region. The soils formed from these are sometimes so rich in ferric hydrate (iron rust) that they might well serve as iron ores elsewhere; often having from 30 to 40 per cent. of that substance. But as these soils are very unretentive, though very productive at first, they are soon exhausted; the abundant rains having apparently deprived them of almost every vestige of lime, and of most of the potash contained in the original rock. To return lime to them would seem to be the first thing needful in restoring their producing powers, and the coral sand of the beaches would offer a cheap source of supply of that substance. A more detailed discussion of some of these points is given further on.

INFLUENCE OF RAINFALL ON SOIL-FORMATION.

Since water is the prominent agent in the process of soil formation, it follows that the variations in its supply, in other words, the greater or less amount of rainfall, must affect materially that process. In addition, and especially in connection with the rainfall, the *temperature conditions*, already referred to, and the *manner of distribution of rains through the seasons* in connection therewith, are potent factors.

Leaching of the land.

One of the most obvious results of an abundant rainfall is the leaching-out of the more soluble portion of the rock constituents that have been formed or set free by the process of weathering.

The extent to which this leaching occurs depends of course largely upon the perviousness of the soil material to water; it is greatest in "leachy" soils, *i. e.*, those in which not only the surface layer but also the substrata are so coarsely sandy as to permit a very rapid passage

of water in all directions. From this extreme, through sandy and clayey loams to heavy clay soils, there is every gradation of perviousness to almost impermeability. Whatever water falls on the latter class of soils will largely run off from the surface, hence cannot leach out of them what, in the case of "lighter" soils, is carried currently into the country drainage.

Composition of sea water.

The usual nature of the substances so leached out is well illustrated in the salts of sea-water, which represent the generalized result of countless ages of this leaching process.

Mean composition of sea water (according to Regnault).

Sodium chloride (common salt).....	2.700
Potassium chloride .....	.070
Calcium sulphate (gypsum).....	.140
Magnesium sulphate (Epsom salt) .....	.230
Magnesium chloride (bittern).....	.360
Magnesium bromide.....	.002
Calcium carbonate (limestone) .....	.003
Water (and loss in analysis).....	96.495
	100.000

The average saline contents of sea water would thus be 3.505 per cent. In twenty-one determinations of the saline contents of the Atlantic Ocean, the percentage ranged from 3.506 to 3.710 per cent. Of this mineral residue, common salt constitutes from about 75 to over 80 per cent.

We see that most prominent among the ingredients mentioned here is common salt (sodium chloride), which forms nearly four-fifths of the total solid contents. Next in quantity are the compounds of magnesium, viz., Epsom salt and bittern, with a very small amount of the bromine compound. Next come the compounds of calcium (lime), of which gypsum is the more abundant, while the carbonate, so abundant on the land surface in the various forms of limestone, is present in minute amounts only, yet enough to supply the substance needed for the shells of shellfish, corals, etc. Least in amount of the metallic elements mentioned is potassium, which, like sodium, exists mainly in combination with chlorine. Calculating the total amounts of the latter substance, we find that it exceeds in weight any one other element present in the salts of sea water, being two-sevenths of the whole amount.

Substantially the same result, with variations due to local causes, is obtained when we consider the saline ingredients of lakes having no outlet, and in which therefore the leachings of the tributary land area have accumulated for ages. The Great Salt Lake of Utah, the land-locked lakes of the Nevada basin, of California, Oregon, and of the deserts of Asia, Africa, and Australia, all tell the same tale, which

may be summarized in the statement that the chlorides of sodium and magnesium and the sulphates of sodium, magnesium, and calcium constitute the bulk of the leachings of the land, while of other substances potassium alone is present in relatively considerable amount.

While the above analysis shows the ingredients of sea water so far as they can at present be directly determined by chemical analysis, yet the presence of many others is demonstrable, directly or indirectly, from various sources. One is, the mother waters from the making of sea salt, in which such substances accumulate so as to become ascertainable by chemical means, and even become industrially available in the cases of potash and bromine. Another is the ash of seaweeds, which is indisputably derived from the sea water, and contains, among other substances not directly demonstrable in the original water, notable quantities of iodine (of which this ash is the commercial source), iron, manganese, and phosphoric acid. Again, the copper sheathing of vessels, as it is generally corroded, becomes more or less rich in silver, manifestly thrown down from the sea water, and the silver so obtained is associated with minute amounts of gold. Copper, lithium, and fluorine likewise have been found in sea water; and it is probable that close search would detect very many of the other chemical elements as ordinary ingredients in minute amounts. This is what must be expected from the fact that few mineral substances known to us are entirely insoluble in pure water, and still fewer in water charged with carbonic acid. The latter is always present in sea water and holds the lime carbonate in solution; on evaporation or boiling, this substance is the first to be precipitated; and thin sheets of limestone from this source are commonly found at the base of rock-salt beds, which, themselves, are evidently the result of the evaporation of segregated bodies of sea water in past geological ages.

Summing up the facts concerning the water of the sea and of land-locked lakes, with reference to the ingredients of soils needful for the nutrition of plants, it appears that the rock ingredients leached out in the largest amounts are those of which the smallest quantities only are required by most plants; while of those specially needful for plant nutrition, only potash is removed in practically appreciable amounts by the country drainage.

Insufficient rainfall.

When, however, the rainfall is either in total quantity, or in its distribution, insufficient to effect this leaching, the substances that otherwise would have passed into the sea are wholly or partially retained in the soil stratum and when in sufficient amount may become apparent on the surface in the form of efflorescences of "alkali" salts. The presence of the latter is therefore almost always an indication of scanty rainfall, and of other important peculiarities which will be considered more fully hereafter.

INFLUENCE OF CLIMATIC CONDITIONS UPON THE PHYSICAL CHARACTER OF SOILS.

While it is not possible to separate strictly the physical or mechanical from the always more or less concurrent chemical differences caused by climatic influences, some general considerations on the former should precede the discussion of the latter class.

EFFECTS OF ARID AND HUMID CLIMATES ON THE FORMATION OF CLAY.

One of the most important modifications produced by scantiness of rainfall on soil formation is the great retardation of the formation of clay from feldspathic rocks (kaolinization) and the sediments derived therefrom. An often-quoted example of this influence is that of the quarries of Syene in Upper Egypt, where most of the great monoliths employed in the construction of the monuments and temples of Egypt were obtained. In this quarry, which has not been worked for at least two thousand years, the rough blocks that were in progress of quarrying when the work was finally abandoned are said to show an almost perfectly fresh surface to this day; and a well-preserved surface is also shown by the obelisks and pillars made of the same material and transported to lower Egypt, where, however, the rainfall is somewhat greater. It is a matter of public note that one of these monuments (Cleopatra's Needle) for some time set up in the Central Park at New York, is in great danger of destruction from the influence of a totally different climate, in which not only the rainfall but the temperature changes are very much greater than in Egypt. Both factors combined will, of course, prove even more destructive than one alone would be, for a change of temperature that has resulted in the opening of fine cracks at the joints of the mineral components, if followed by a rain and a subsequent freeze, may produce a greater effect in a few days than a thousand years of Egyptian climate would have accomplished. In the case of the obelisk at New York, the physical effects just mentioned are doubtless the chief factors of destruction; while the chemical process of kaolinization is too slow to be noticeable at once, although it is clear that it will be enormously accelerated by the breaking-up of the rock caused by the purely physical agencies.

A similar contrast is found in comparing the granitic rocks of the southern Alleghanies with the corresponding rocks in the arid plateau region west of the Rocky Mountains, as well as in California and Arizona. The sharpness of the ridges of the Sierra Madre, and the roughness of the hard granitic surfaces, contrasts strikingly with the rounded ranges formed by the "rotten" granites of the Atlantic slope, where sound, unaltered rock can sometimes not be found at a less depth than forty feet. What is true of granite holds correspondingly, of course, in the case of other rocks.

The inference is that a corresponding difference should manifest

itself in the soils formed under the influence of these diverse climatic conditions; and even the most cursory observation shows this to be the case. The result may be expressed in the general statement, that while the soils of the Atlantic slope are prevalently loams, containing considerable clay, and even in the case of alluvial lands oftentimes very clayey or heavy, the character of the soils of arid regions is predominately sandy or silty, with but a small proportion of clay, unless derived, directly or indirectly, from pre-existing formations of clay or clay shales. Of course the character of these "sedentary" clay soils is substantially independent of climate, their substance having been formed in past geological ages.

LIGHT SOILS PREDOMINATE IN ARID CLIMATES.

This incoherence of the soil material in arid climates, resulting from the scarcity of clay,* becomes obvious to the traveler in the sand and dust storms that sometimes annoy him while traversing, *e. g.*, what has been conventionally known as the "Great American Desert," a desert only so long as the life-giving influence of water is withheld from it. Droughts may render the surface of the country in the Atlantic States, or in Europe, as dry as the great plains themselves; yet away from highways or cultivated fields little or no dust will ordinarily be raised by the strongest wind, because of the coherence of the soil, which will generally be found covered by a hard-baked crust. In the arid region, under the same conditions, a mere puff of wind may raise a cloud of dust, and a wind storm becomes almost unavoidably a sand or dust storm also. "Dust soils," which during the dry season are even in their natural condition so loose as to rise in clouds and render travel very uncomfortable, are not uncommon in Washington and adjacent parts of Oregon, on the uplands bordering the Columbia and Snake rivers. The mechanical and chemical analyses of three such soils, given in the table below, will convey some idea of their peculiarities in both respects.

The same general facts are known of the other arid regions of the globe, whether in Asia, Africa, or Australia.

* It must be distinctly understood that what is meant here by "clay" is not the mineral kaolinite, but the gelatinous, plastic "colloidal" substance that results from its physical disintegration, and alone plays the part of rendering the soils coherent.

Dust soils of arid region.

CHEMICAL ANALYSIS OF FINE EARTH.

	17	37	79
	Atahnam Prairie, Yakima Co., Wash.	Rattlesnake Creek, Kittitas Co., Wash.	Plateau on Willow Cr., Morrow Co., Oreg.
Insoluble matter	71.67	78.33	79.21
Soluble silica	5.11 } 76.78	2.20 }	2.30 }
Potash (K_2O)	1.07	.70	.89
Soda (Na_2O) .....	.35	.24	.05
Lime (CaO)	2.00	2.08	1.37
Magnesia (MgO)	1.34	1.47	1.08
Br. ox. of manganese (Mn_2O_4) .....	.04	.07	.06
Peroxide of iron (Fe_2O_3)	6.88	6.13	5.63
Alumina (Al_2O_3)	7.91	6.12	6.02
Phosphoric acid (P_2O_5) .....	.13	.18	.18
Sulphuric acid (SO_3) .....	.02	.02	.03
Water and organic matter	2.82	2.35	2.55
Total	99.33	99.90	99.35
Humus	4.10	.....	.44
Hygroscopic moisture	4.98	3.20	4.92

MECHANICAL ANALYSIS OF FINE EARTH.

Clay .....	.93	3.59	1.27
Sediment of <.25 millimeters hydr. val	30.93	13.06	32.29
Sediment of .25 to .5 millimeters	3.20	5.82	12.75
Sediment of .5 to 2.0 millimeters	7.18	27.37	37.51
Sediment of 2.0 to 8.0 millimeters	21.88	43.78	10.92
Sediment of 8.0 to 64.0 millimeters	32.39	4.57	3.97
Total	96.57	98.18	98.72

Several points of interest that will be discussed in detail further on are illustrated in this table. In their chemical composition the three soils are very good illustrations of generalized soils of the arid region; they also show that the "clay" of physical analysis is not even approximately represented by the "alumina" of the chemical analysis; and that, moreover, the latter substance is not contained in these soils in the form of clay only, since the amount of "soluble silica" is far below that of alumina, while the reverse should be true if they were originally combined to form clay.

As regards the physical composition, "clay" is shown to be present in very small amounts only; there is a good deal of the finest silt, <.25mm.; and then there occurs a conspicuous break in the small amounts of sediments just above that point. It may be casually mentioned here that soils of this character are irrigated with difficulty, the water penetrating so slowly that ditches must be run a few feet apart and the flow continued for a considerable length of time in order to soak the land.

It will also be noted that the percentages of the mineral plant food in these soils are quite large, and that according to all experience they should be found profusely and permanently productive. This forecast is abundantly confirmed by local experience.

STRONG SOILS.

But so generally has the idea of inherent fertility been associated, in the humid regions, with soils of more or less clayey character, that the terms "strong," "substantial," "durable" are habitually applied to them in contradistinction from "light," "unsubstantial" ones of the sandy or silty type. Hence the newcomer will frequently be suspicious of the productiveness and durability of soils in the arid region that experience has proved to be of the highest type in both respects.

The clayey soils that *do* occur in the arid regions (in California and Spanish America, generally known as "adobe") owe their existence to one or both of two precedent conditions. Those occupying upland slopes are mostly—though not invariably—directly derived from the disintegration of clay shales that either underlie or occupy a higher position on the slope; they are therefore either sedentary (soils in place) or colluvial, and derive their clay from that which was formed in former geological ages. The valley adobe lands, on the contrary, are mostly paludal or swamp formations (therefore not formed under "arid" conditions), and represent either the finest materials that remain suspended in slack water, from any source, or sometimes the direct washings of the clayey hill soils, above mentioned. Examples of both kinds are abundant in the Great Valley of California as well as in the Coast ranges of that state.

GREAT DEPTH OF SOIL IN ARID CLIMATES.

But it is not only in this point that the physical composition of the soils of arid climates differ from those of humid regions. Another point of great importance is that the difference between soil and subsoil, which is so striking and important in regions of abundant rainfall, is largely obliterated in arid climates. Very commonly hardly a perceptible change of tint or texture is found for depths of several feet; and what is more important, material from such depths, when thrown on the surface, oftentimes subserves the agricultural uses of a soil nearly or quite as well as the original surface soil. The unconcern with which irrigators proceed to level or otherwise grade their land, even though this may involve covering up large areas of surface soil with subsoil from several feet depth; the rapidity with which the red loam of the placer mines of the Sierra Nevada foothills is recovered with the natural forest growth of the region, are examples familiar to the residents but surprising to newcomers, who are accustomed to dread the upturning of the subsoil as likely to deprive them of remunerative crops for several years, until the "raw" subsoil has had

* It is to be regretted that in the publications of the U. S. Geological Survey this name has been erroneously applied to the loam commonly used in the construction of adobe houses. Agriculturally it means "a heavy clay soil," such as could not be used in building.

time to be "vitalized" by the fallowing effect of the atmosphere, and to acquire the needful amount of humus, or vegetable mold.*

The cause of this difference is readily understood when we consider what it is that causes the contrast between soil and subsoil in humid climates. As before stated, soils are there, as a rule, richer in clay; this clay, becoming partially diffused in the rain water when a somewhat heavy fall occurs, percolates the soil in that condition and tends to accumulate in the subsoil; the result being that, almost without exception, the subsoils of the humid regions are very decidedly more clayey than the corresponding surface soils. It is only in alluvial lands formed by periodic overflows, which bring down deposits of varying nature at different times, that any material departure from this rule is found; more rarely it occurs in the case of colluvial soil overlying sandy beds, but supplied with clayey matter from a higher-lying outcrop.

But not only does this clay water tend to render the subsoil more compact and heavy, making it less pervious to water and air, but it is assisted materially in this by the action, discussed below, which tends to leach the lime carbonate out of the surface soil into the subsoil. The accumulated clay is thus frequently more or less cemented into a "hardpan" by lime, partly in the form of carbonate, partly in that of zeolitic (hydrous silicate) compounds; adding to the compactness of the subsoil, and therefore to the usual specific difference between soil and subsoil, viz., the deficiency or absence of humus, and the difficulty of penetration by and aeration of the roots of plants. This point will be further considered below.

INFLUENCE OF CLIMATIC CONDITIONS UPON THE FORMATION OF HUMUS.

Succeeding more or less closely, in time, the physical and chemical agencies upon which depend the formation of soils from rocks and the continued decomposition of the rock powder in soils themselves, there comes another which is most intimately connected with plant growth, and scarcely second in importance to those already referred to. This is the decay of vegetable matter in the soil and the formation of what, in a comprehensive way, is known as humus or vegetable mold—the dark-colored, sometimes jet-black remnant of vegetable decomposition under at least partial exclusion of air. While now known not to possess that exclusive importance for vegetable nutrition that was at one time attributed to it, humus is still recognized as one of the most important soil ingredients for the purposes of practical agriculture; and

*In the case of a cellar 7 to 10 feet deep, near Nevada City, Cal., the red subsoil mass dug out was spread over a part of a vegetable garden close by, and as a venture the annual vegetables—tomatoes, beans, watermelons, etc.—were sown just as usual. They not only did well, but even better than the portions not covered, which had been cultivated for a number of years and were somewhat exhausted thereby. Even material from 30 feet depth has acted similarly.

as its formation is directly dependent upon climatic conditions, its variations in accordance with them form essential points of difference between the soils of humid and arid regions.

Vegetable matter exposed to the action of the air alone will, in the course of time, be completely destroyed by the slow process of combustion (*eremacensis*), which is unaccompanied by any essential fermentative action and is materially assisted by an elevated temperature. When submerged in water it undergoes a very different process, namely, a gradual conversion into a brown mass, of which the extreme result is peat. The coffee-colored waters of peat bogs prove that this substance, or a portion of it, is soluble in water; and these brown waters are distinctly acid to test papers and sometimes even to the taste. Hence the popular designation of soils formed or existing under such conditions as "sour," is strictly correct; and it is well known that the correction of such lands by means of drainage, and the neutralization of the acidity in the soil (usually, in practice, by marl-ing), are conditions-precedent of their profitable cultivation.

Peat bogs, properly so called, can exist only in cold-temperate, humid climates; not only because the peat moss, which forms their chief vegetation, can not flourish in dry air, but also because the vegetable matter accumulating under water in warm regions undergoes a more rapid fermentation, whereby much of it is converted into gaseous products (carbonic and marsh gas), and the peaty or humus residue is greatly less in amount. But the conditions for the formation of "sour" soils may be realized in *any* climate, in the presence of water, as in the "tule" or marsh lands of California, as well as of Louisiana and Florida, or in the heads of ravines where springs or oozes of water constantly flow. But in the marshy Arctic lowlands or tundras the low temperature maintained even during the short summer renders the progress of humification extremely slow, preventing the formation of true peat even where the peat moss can maintain its existence.

When, on the contrary, vegetable matter decays *underground* in well-drained land, the process of humification has a result different from either of the two preceding cases. The humus formed is of a darker and sometimes jet-black tint, and it imparts no color to water percolating through the soil, being completely insoluble. It is this kind of humus that is desired by the farmer everywhere; it is hailed by him as the mark of high productiveness in the case of new lands, and he considers the maintenance of a proper proportion of it in the cultivated land as essential to profitable culture.

It should be noted right here that the brown humus of bogs is not only neutralized in its acidity by lime, but it is also rendered insoluble in water by its action; and in the course of time is transformed into true, black, insoluble humus.

A product intermediate between peat proper and true soil humus is

found forming the surface of the primeval forests of the coast region of northwestern America, from middle Oregon to Alaska. It is known to the inhabitants as "duff," probably from its resemblance to the holiday pudding of seafaring men, that is usually colored by molasses or brown sugar. The natural "duff" is the result of the decay, above ground, of the countless trunks of fallen trees that so commonly obstruct the passage of any but the most agile pedestrian in those regions, and upon which the new generation of trees frequently finds a most congenial starting point and foothold. In the course of time, in a climate in which daily rains are the rule rather than the exception, these trunks flatten out and in the aggregate form a surface covering occasionally several feet in thickness, on which rank mosses, *Linnæa*, various pyrolas, prince's pine, and similar plants flourish in dense masses, while grasses or anything else affording pasturage are conspicuously absent. The brown tint of the surface layers of the "duff" gradually deepens as the depth increases, and finally there is an insensible transition into normal, black soil.

INFLUENCE OF ARIDITY UPON THE FORMATION OF HUMUS.

It is easily seen that under the influence of hot, rainless sunmers, the process first mentioned above, viz., eremacausis or slow combustion, which leaves little residue beyond the mineral ash of the vegetable matter, must prevail very largely; and that, exceptional circumstances apart, the previous soils of the arid regions are likely to contain less humus than those of humid climates. Broadly speaking, actual examination amply proves this presumption to be correct, and among the agricultural practices which prove very successful in the eastern United States but largely fail west of the 100th meridian is one bearing on this very point. Straw or strawy manure cannot be profitably plowed in, in its raw condition, in the arid regions, because of its failure to decay and become a portion of the soil within any reasonable limit of time. Hence these precious materials were, during the earlier years of Californian agriculture, most commonly burnt to get them out of the way, so as not to interfere with the success of crops by keeping the soil too open, thus preventing the germination and rooting of the grain. The rapid burning of the straw really did little more than to accomplish in a short time what in the course of nature would have taken two or three years by the agency of slow eremacausis.

Ordinarily it was only through the winter months that any material amount of humification could take place under the influence of moisture and an only moderately low temperature.

Climatic conditions thus compel the farmer of the arid region to "cure" or compost his straw or manure before using them on the field, unless, indeed, he can so far control the climate by the command of irrigation water as to restore, substantially, the humid conditions necessary for the rapid fermentation of manure in the soil itself, and for

the humification of dry straw or refuse. The extra labor thus involved is a material drawback to the free utilization of stable-yard manure, and of all dry vegetable refuse of the farm, and there thus arises a natural inclination toward the use of the easily applicable commercial fertilizers whenever fertilization becomes necessary. That the openness of most of the soils, and the high summer temperature, must in a measure modify the selection and the mode of application even of these is obvious. To be effective and utilized to the best advantage they must be put in to a greater depth than would be required where the surface soil is not liable to become air-dry, and perhaps quite hot, during the summer days; for otherwise the roots would be induced, in following the direction of greatest food supply, to come within dangerous proximity to the arid surface.

These considerations apply mainly, of course, to the characteristic soils of arid climates—the silty and sandy ones, which are the result of a general process, and not of the disintegration, in place of clayey beds or clay shales, or of slow deposition in river or littoral swamps. For in these the atmospheric influences are so far limited by their closeness, as well as by their tenacious retention of moisture, that the process of humification can proceed under much more favorable conditions; and hence we find among this class of soils (black adobe) very much larger humus percentages, approaching nearly to those of the soils of the Mississippi Valley.

Few of the characteristic upland soils of the arid region contain over .40 per cent. of true humus,* the fruit-growing “mesa” soils of south California mostly fall below one-fourth of one per cent. (.25 per cent.) In the humid region of the cotton states three-fourths of one per cent. is a common amount, and few even of the pine-woods soils fall below one-half per cent. This difference is important because the humus of the soil is the repository of that highly important soil ingredient, nitrogen, the replacement of which is the most costly of all where clovers cannot be used for green manuring.

INFLUENCE OF CLIMATIC CONDITIONS UPON THE CHEMICAL PROCESSES IN AND CHEMICAL NATURE OF SOILS.

Owing to their intimate interdependence the chemical processes that are constantly active in soils have to some extent been mentioned already in connection with the discussion of the physical characters. They will now be considered more in detail in their connection with climatic conditions.

THE LEACHING PROCESS.

One material difference caused by a copious rainfall as compared

*That is *matière noire* as determined according to Grandjean's process of extraction, the only method by which unhumified organic débris can with certainty be excluded from the determination. Both combustion and extraction with alkaline lye yield results of no value, varying widely with the season in one and the same soil.

with a scanty one, has been mentioned in the current leaching out of the easily soluble alkali salts, notably those of sodium, and to some extent of potassium also, together with certain easily soluble earthly compounds (sulphates and chlorides of calcium and magnesium), and occasionally of other locally abundant soluble substances. These salts, being carried through the soil into the country drainage, gradually accumulate in the basins finally receiving the same, whether oceans or inland lakes.

In arid regions these salts are, on the contrary, retained in the soil to a greater or less extent; they tend naturally to accumulate in the lower ground, toward which they are carried by the occasional rainfalls, as well as by the general seepage.

Before considering in detail the effects of this retention of the salts commonly known as soluble, it is necessary to discuss the effects of climate upon another substance, viz., lime carbonate, commonly presented to us in the form of limestone and chalk.

LIME CARBONATE IS SOLUBLE.

Although ordinarily considered insoluble in water when in the form of marble, limestone, or chalk, lime carbonate is yet sufficiently soluble in the soil water—always more or less charged with carbonic acid—to be materially affected by the leaching process. While much less soluble than the salts of potassium, sodium, or magneisum, and also less than gypsum or lime sulphate, yet the constant tendency is to leach it out of the surface soil into the subsoil, and from the soils of the uplands into those of the lowlands. We shall, therefore, expect to find, ordinarily, each subsoil a little richer in lime carbonate than its surface soil; and the valley soils more calcareous than those of the adjacent uplands. A comparison of a series of such analyses clearly demonstrates the overwhelming prevalence of this difference, so far as the contents of easily soluble lime are concerned; but owing to the fact that the surface soil is more fully exposed to atmospheric influences than the subsoil, the former may at times be found to contain more actual *carbonate* than the subsoil (where it often suffers transformation into other compounds). Such a time is at the end of the dry season, during which (as Storer has first shown) lime carbonate is formed from other compounds of lime; a highly important part of the "fallowing" process. But during the following rainy or winter season the carbonate is again washed into the subsoil, so that in humid climates it may in spring be almost absent from the surface soil itself.

But this being so, it follows that in arid climates, in which the rainfall is insufficient to leach the soil even of its very easily soluble alkali salts, the lime carbonate must of necessity accumulate to even a greater extent than the former. We should therefore expect to find the soils of the region west of the 100th meridian in the United States, and generally those of arid regions everywhere, richer in lime than those

of the humid regions, and particularly of those having abundant and frequent rains during a warm summer. For under the latter conditions the fermentation and oxidation of vegetable matter in the soil is very active, generating a large amount of carbonic acid, which is taken up by the soil water and readily dissolves lime carbonate; and the rainfall being sufficiently copious, this solution is carried through porous soils and subsoils into the country drainage.

Striking exemplifications of this action are sometimes seen in the case of lands either naturally very calcareous, or made so by marling, and underdrained by tile. After a number of years, not only will the tile be found incrusted more or less with lime carbonate in the form of "sinter" or tufa, but sometimes, where the flow is habitually somewhat arrested, the accumulation may become so great as to seriously obstruct small tiles, which it therefore is inadvisable to use in such soils. The principle involved here is precisely the same as that upon which depends the formation of stalactites in limestone caves, as well as that of the latter themselves.

We shall thus expect to find the upland soils in the region of summer rains relatively poor in lime; unless indeed they are underlaid more or less directly by, or derived from, some geological formation rich in that substance, from which the supply is kept up. Such is the case in the "residual" soils of the "prairies" of the Mississippi valley; and generally in limestone regions. And since, lime is an exceedingly important soil ingredient, conditioning very materially the thriftiness of soils, it has in the humid regions become a common adage that "a limestone country is a rich country." This is true, at least, wherever the limestones are not too pure, as is mostly the case in North America; while in the portions of Europe in which chalk—an exceedingly pure limestone—is the country rock, "poor chalk land" is frequently spoken of.

But in the arid regions no such distinction is popularly made. This is natural since, as we have seen, lime carbonate is constantly accumulating in their soils, and, therefore, it is not to be expected that the connection with a limestone formation should make any material difference in their quality.

This leaching process is of such great importance, both theoretically and practically, as influencing the thriftiness of soils, and, therefore, the agricultural practice of the humid and arid regions respectively, that a somewhat detailed presentation and discussion of the facts is called for; the more as these have never, so far as I am aware, been definitely observed or placed on record heretofore.

For the study of this question an extended comparison of the composition of the soils of representative arid and humid regions is required; and I have, for this purpose, gathered together and tabulated for comparison, all the available analyses of soils from the humid and arid portions of the United States, respectively.

COMPARISON OF SOILS FROM THE ARID AND HUMID REGIONS OF
THE UNITED STATES.

To give in detail the large number of analyses upon which the following table is based would exceed the proper limits of this paper. As the greater portion of them are in print in publications not difficult of access, references are given to the records from which the data have been derived; only as regards the soils of Washington and Montana, the data are still in manuscript only, and form part of the records remaining in the writer's hands since the regretable cessation of the Northern Transcontinental Survey, prosecuted from 1880 to 1883, under the auspices of the Northern Pacific Railroad.

SELECTION OF DATA FOR COMPARISON—METHODS OF ANALYSIS.

As it is absolutely essential that in making such comparisons the analyses should have been made by exactly the same methods, I have included in it exclusively those for which this condition is with certainty fulfilled, namely, the several series made under my own direction from 1857 to the present time, and those made in connection with the geological surveys of Kentucky and Arkansas (first under the direction of Dr. David Dale Owen, and since his death under that of others), mostly by Dr. Robert Peter, the veteran chemist of the Kentucky survey at this time. Some, of which the comparability in this respect is probable, but not certain, published in the reports of other states, have been omitted because of this uncertainty.

SOILS FROM CALCAREOUS AREAS OMITTED.

Another consideration has governed the omission from the present comparison of a large number of soils that have been analyzed on the same plan. It is plain that if we were to include such as have, in their origin, a more or less direct connection with calcareous formations, either as residuals still underlaid by such formations, or as alluvials and colluvials derived from the same, the climatic influences would be obscured and the comparison still further vitiated by the accident of the numerical proportion between the number of such soils and those derived from non-calcareous materials, that happened to have been chosen for examination. Tennessee forms a case in point. It happens that all of the seventeen soil analyses made for that state during the census work of 1880 are more or less directly connected with calcareous formations, which underlie the prominent agricultural subdivisions thus far studied. From this cause Tennessee is unrepresented in the list of states below; and for the same reason a very large proportion of Dr. Peter's analyses of Kentucky soils are thrown out, *e. g.*, the well-known "blue-grass region," and generally that portion of the state covered by limestone formations.

On the same ground, of one hundred and forty-one analyses of Arkansas soils by D. D. Owen and Dr. Peter, only thirty-eight could be

admitted to comparison. In this case, as in that of Mississippi and Louisiana, the large proportion of "bottom soils" derived from the calcareous clays of the Port Hudson beds, and from the loess area, has necessitated the body of the exclusions.

In Mississippi the soils of the cretaceous and tertiary prairies, of the loess proper, and those of the heavy soils of the alluvial area (Yazoo bottom) that are directly derived from the Port Hudson clays, are excluded; but not those of the recent alluvium, nor those of the tributaries from the uplands. Thus out of one hundred and thirty analyses thirty-three have been excluded. The analyses of the brown loams underlying the loess, though somewhat influenced by the subjacent formation, are nevertheless retained.

Of twenty-five available analyses of Louisiana soils, seven are excluded because of their direct connection with the Port Hudson and loess materials.

Of 40 available analyses of Texas soils, all but 7 are from "prairie" areas known to be underlaid by calcareous materials. The seven forming the somewhat doubtful exception (because in part from areas underlaid by calcareous tertiaries) are from points lying both in the humid and arid portions of the state, and therefore would not make a fair showing for either. The same is true of the few analyses of soils from the Indian Territory.

Of 56 available analyses of Alabama soils, all but six, representing well-known "prairie" areas, enter into the averages.

All known analyses of Florida soils, seven in number, are included.

Of 60 analyses of Georgia soils, 17 representing the essentially calcareous areas of what is known as "Northwest Georgia"—palaeozoic terranes—are excluded from the comparison, together with three others from the tertiary region.

All available soil analyses from South Carolina are included. So also are those from North Carolina, except those made for the geological survey of the state, the method used in these analyses being unknown and apparently different from that adopted in the census work of 1880.

The same general system of selection and exclusion has, of course, been put in force on the available soil analyses from the arid regions; mainly represented thus far by California, Washington, and central Montana. As is well known to geologists, these are regions very deficient in limestone formations, so that it is difficult to obtain material for a home supply of lime for building and other purposes. It is true that the rock material of the cretaceous and tertiary beds covering large portions of these regions is often more or less calcareous, and would by disintegration yield a slightly calcareous average material. But the same is true of a large portion of the humid region in areas which, nevertheless, have not been ruled out from this comparison. Wherever it is known that a specially calcareous deposit is near at

hand, and may have contributed an extra proportion of calcic carbonate, the analysis has been ruled out; and on the same ground as in the case of the soils of the lower Mississippi, where the old swamp (Port Hudson) beds have been an essential contributory factor, the corresponding soils from the troughs of the valley of California have been excluded. Thus of a total of 236 analyses of California soils, 38 have been excluded from the averages.

Out of 80 analyses of Washington soils, four showing unusual proportions of lime were ruled out on suspicion that there might be a special source of lime involved. In the rest the range is so steadily from a little below one to a little over two per cent., that there was no basis for a discrimination, the more as the country is destitute of limestones and, save at a few points, even of any obviously marly formations.

In the case of Montana, 14 out of 43 soils have been ruled out, mostly on suspicion of, but partly because of, known connection with limestone formations; as, *e. g.*, in the case of lands at the foot of the Big Snowies, a limestone range forming part of the northern rim of the Judith basin.

The rule thus having been applied, as impartially as possible, to the soils of both the humid and arid regions, I believe that the conclusions flowing from a discussion of the results of the comparison are entitled to as much weight as are those of any comparison based on large numbers of observations made, not with reference to the special point under consideration, but with a practical object of which the governing conditions were more or less uncertain and required to be ascertained by a process of elimination.

The table gives, first, the averages for each ingredient for each of the states represented, the number of analyses from which the averages are derived being given in each case. These averages are given separately for the states of the humid and the arid regions respectively; and at the base of each group the grand average is shown in two forms. The first gives the figures as derived from the aggregate number of soil analyses in each great group, being 466 for the humid and 313 for the arid, divided into the totals resulting from the summation of each ingredient for the whole, 466 and 313, respectively.

The second form is that in which the soils of each state are considered as representative of the general character of such state, as the result of intentional selection; such as actually occurred in the cases of those included in the census work of 1880. The figures given here are therefore the result of a summation of the state averages as such, and of their division by the number of states represented.

It may be cursorily noted here that while these two modes of presentation do change the figures a little, yet in either form the same general result is outlined with striking accuracy.

It will be noted that in some cases the averages for states are not all

based upon the same number of analyses. This happens mostly because of omissions made in determinations, occurring most frequently in the case of the item "soluble silica." It must be understood that in the earlier work the importance of ascertaining this point in every case had not been thought of. Hence it is entirely wanting in the analyses representing Kentucky and Arkansas and in all the earlier work relating to Mississippi. This explains why in some cases the averages of the two first columns (insoluble residue and soluble silica) do not sum up correctly in the third column, which, where both determinations always have been made, should be the sum of the two preceding.

To amplify the evidence as much as possible there are also given three analyses from Colorado, New Mexico, and Utah, made for the purpose of ascertaining the probable success of sugar beets, and therefore, as it happens, representing characteristic "mesa" or plateau lands. These analyses were made in the laboratory of the California Experiment Station by Mr. Hubert P. Dyer, chemist to the Utah beet sugary near Lehi.

Below these is given the averages from nine soils analyzed at the Wyoming Experiment Station, and representing the surface soils of the six culture experiment stations of that state. The subsoils given in the same publication are omitted because some of them are manifestly in contact with calcareous formations, so that the lime average would be grossly exaggerated, as in the case of the soil from New Mexico, which has been excluded from comparison for the same apparent reason. Moreover, this series is not included in the averages of the three soils above, because of divergencies in the method of analysis. Nevertheless, the general results are precisely in line with the remainder of the averages for the arid region.

REFERENCES TO SOURCES OF DATA.

For the analyses of soils from the states of North and South Carolina, Georgia, Florida, and Alabama, Report of U. S. Census for 1880, vol. 6.

For the states of Mississippi, Louisiana, and Arkansas, *ibid.*, vol. 5; from reports of the respective geological surveys and reconnoisseances, and partly from manuscript records, still unpublished.

For Kentucky, the reports of the Geological Survey of Kentucky from 1856 to the present time; analyses by Dr. Robert Peter.

For California, the several reports of the College of Agriculture and Experiment Station of the University of California from 1877 to the present time.

For Washington and Montana, the manuscript records of the Northern Transcontinental Survey from 1880 to 1883.

For Utah, New Mexico, and Colorado, manuscript record of work by Hubert P. Dyer, chemist to the Utah Sugar Company, Lehi, Utah.

For Wyoming, Bulletin No. 6 of the Wyoming Experiment Station, May, 1892.

Average composition of soils in the humid and arid regions of the United States.

Name of state.	No. of soils averaged.	Insoluble residue.	Soluible silicate.	Total insoluble residue and soluble silicate.	Potash.	Soda.	Lime.	Magnesita.	Browm oxide manganese.	Peroxide of iron.	Alumina.	Phosphoric acid.	Hygroscopic moisture.	Temperature of adsorption, C.	Water and organic matter.	Total.	Soluble phosphoric acid.	Humus.	Carbonic acid.	Available inorganic matter.	
North Carolina	20	81.627	3.595	85.133	.145	.957	.088	.080	.071	4.718	5.713	.118	.061	3.977	100.163	4.282	21.1	.....	.....	.....	.....
South Carolina	11	83.493	3.425	86.919	.123	.059	.114	.155	.083	2.771	5.709	.097	.108	3.809	100.039	4.228	23.6	.....	.....	.....	.....
Georgia	40	86.006	3.587	88.954	.150	.005	.076	.099	.090	2.751	4.018	.111	.096	3.619	100.029	3.541	17.0	4.383	.....	.....	.....
Florida	7	94.277	1.172	95.449	.101	.034	.091	.027	.027	1.049	1.049	.091	.069	1.004	100.136	2.064	24.4	.....	.....	.....	.....
Alabama	50	81.576	4.893	86.469	.231	.073	.169	.210	.120	3.814	2.669	.134	.053	4.039	100.011	7.066	20.2	.....	.....	.....	.....
Mississippi	97	85.870	4.391	88.714	.276	.109	.145	.312	.137	2.613	4.069	.091	.029	3.331	100.176	5.410	15.4	.....	.....	.....	.....
Arkansas	38	88.539	.165	88.539	.081	.081	.430	.205	.008	3.511	.150	.045	.009	3.704	99.931	2.473	1.845	.....	.....	.....	.....
Kentucky	155	78.393	6.837	86.731	.199	.004	.081	.193	.197	6.008	3.523	.109	.038	3.691	100.862	6.056	24.5	.....	.....	.....	.....
Louisiana	18	84.031	4.212	87.687	.216	.091	.108	.225	.133	3.131	4.266	.113	.052	3.644	100.178	4.650	18.5	.....	.....	.....	.....
Total for humid region.	466	84.472	3.873	88.126	.187	.071	.112	.209	.126	3.455	4.008	.114	.065	3.557	100.093	4.189	20.9	.....	2.53	.....	.....
Averages by states .....	.....	84.472	3.873	88.126	.187	.071	.112	.209	.126	3.455	4.008	.114	.065	3.557	100.093	4.189	20.9	.....	2.53	.....	.....
California	198	67.882	8.960	79.842	.644	.277	1.075	1.488	.062	6.393	8.721	.083	.048	4.396	100.048	5.025	.....	03	1.040	1.148	.48
Washington	76	75.021	3.673	78.966	.777	.249	1.378	1.171	.049	5.530	6.063	.173	.028	5.226	99.952	5.941	.....	.....	1.155	.403	4.67
Montana	39	66.141	6.235	72.376	1.005	.226	2.483	1.494	.057	4.459	7.145	.178	.029	7.133	99.935	8.712	.....	.....	3.321	2.398	1.82
Total for arid region	313	70.565	7.266	76.135	.729	.264	1.362	1.411	.059	5.752	7.888	.117	.041	4.945	99.993	6.281	.....	.....	1.839	1.316	2.32
Averages by states .....	.....	69.681	6.289	75.052	.825	.251	1.645	1.384	.056	5.431	7.399	.144	.035	5.585	99.978	6.859	.....	.....	1.830	1.316	2.32
Utah	1	79.20	4.70	83.90	.709	.404	1.237	.848	.019	7.770	1.477	.160	.003	3.707	100.232	6.02	.....	.....	.....	.....	.....
New Mexico	1	63.20	7.32	70.52	.732	.176	*10.060	1.007	.020	4.031	2.560	.103	.082	3.197	99.849	-7.390	.....	.....	.....	.....	.....
Colorado	1	69.61	11.12	80.73	.964	.113	.706	.845	.006	6.640	5.560	.090	.033	4.430	100.117	.....	.....	.....	.....	.....	.....
Average of the three	70.67	7.71	78.38	.801	.231	.971	.900	.015	6.147	3.109	.117	.039	3.778	100.099	.....	.....	.....	.....	.....	.....
Wyoming	9	75.79	2.45	78.24	.72	.47	2.67	1.45	.....	3.32	5.85	.18	.10	4.79	99.69	.....	.....	.....	1.90	.....	.....

* Omitted in the average.

LIME.

Considering in this table, first, the ingredient under discussion above, viz., lime, a glance at the columns for the two regions shows a surprising and evidently intrinsic and material difference, approximating in the average by totals to the proportion of 1 to 12; in the average by states, 1 to $14\frac{1}{2}$. This difference is so great that no accidental errors in the selection or analysis of the soils can to any material degree weaken the overwhelming proof of the correctness of the inference drawn upon theoretical grounds, viz., that the soils of the arid regions must be richer in lime than those of the humid countries. For the differences in derivation would, in view of the prevalence of limestone formations in the humid regions concerned, produce exactly the reverse condition of things from that which is actually found to exist; and if further proof were needed it can readily be found in the detailed discussion of the analyses of the soils of the arid areas forming the contrast. This shows that, for instance, in Washington highly calcareous soils are directly derived from the black basaltic rocks; while similarly calcareous lands are found in California to be outcome of the decomposition of granites, diorites, and lavas.

It is not easy to overrate the importance of this feature of the soils of the arid region, as it is intimately connected with other theoretically and practically important facts which will be discussed later.

Now, if it be true, that "a limestone country is a rich country" in the humid regions, and, if, as the tables show, the soils of the arid regions are all calcareous to the extent to which that property serves its general purpose,* then it must also be true that when the deficiency of rainfall in the arid regions is supplied by irrigation, the soils of the arid regions should be exceptionally productive as compared with those of the regions of summer rains.

I think experience shows that this is strictly true, and that in the arid region "poor" soils are very much less common than in the humid climates. As farmers would express it, the land is "all marled" in its natural condition, and a smaller area can there, on the average, be made to sustain a family.

Is there not here a clue to the fact that has excited the surprise of many, viz., that arid or irrigation countries have in past times been the chosen abodes of dense populations, whether about the rock-hewn cities of Syria or in those of Arizona? Is it not true that the "desert" is a desert merely in appearance, and that the life-giving water brought by

* The lime percentage usually mentioned in text-books as necessary to the "calcareous" character of a soil ("vigorous effervescence with acids") implying not less than 4 per cent. of the carbonate, is very much greater than is actually necessary to impart all the desirable and characteristic agricultural and vegetative features to soils that depend upon the action of lime. Very much less is, moreover, required for that purpose in sandy soils than in those which contain much clay. See Report of Tenth Census, vol. 5, page 64.

the hand of man is all that is needed to convert it into a land where milk and honey flow? According to recent experiments, even the shifting sands of the Sahara desert become productive when irrigated

UPLAND AND LOWLAND VEGETATION IN THE ARID AND HUMID REGIONS.

In the humid regions there is always a marked difference between the vegetation of uplands and lowlands, arising not merely from the difference in moisture supply, but evidently of a specific nature. When we discuss the characteristic plants in detail, it becomes obvious that it is lime vegetation that forms the characteristic difference in most cases; and by way of counter-proof we find that when the uplands are themselves of a calcareous nature, a part of the valley flora ascends into them. To mention one of many instances: The tulip tree (*Liriodendron*, Whitewood) is a lowland tree over the greater part of its area of occurrence; but in the loess or cane-hills area of the Southwest, as well as in the cretaceous (limestone) hill country of Mississippi, it is conspicuous in the uplands. The same is true of the black walnut, the linden, and many other trees and shrubs characteristic of limy soils.

In the arid region, on the contrary, the main difference observable in upland and lowland vegetation (outside of mountain influences) is entirely referable to moisture conditions; the proof being that so soon as the uplands are irrigated the lowland flora, so far as it is distinct, takes possession. This uniformity of upland and lowland vegetation is particularly conspicuous in the comparatively restricted floras of the Pacific northwest—eastern Oregon and Washington, and Montana, where one may travel for days over hill and dale and plains, all equally arid, with scarcely a change in the character of the flora, especially during the dry season. Both uplands and lowlands being nearly equally calcareous, there is no reason for any material difference.

FORMATION OF CALCAREOUS HARDPAN IN SUBSOILS.

As stated above, subsoils are in all ordinary cases richer in lime compounds than the overlying surface soil, owing to the solubility of lime carbonate in the soil water, which, being followed by air when rain ceases, gradually deposits the lime in the lower layers of the arable stratum, by the well-understood process of aeration.

In humid climates, however, the frequent rains, so very variable in amount, rarely allow of the accumulation of very large amounts of this substance at a particular depth. Hence, while in such regions (the prairies of Mississippi and Louisiana) we often find, in soils overlying calcareous strata, a formation of whitish concretions (commonly known as “white gravel”) of lime carbonate, yet the formation of continuous layers or sheets of subsoil cemented by lime is not frequent.

In the arid regions, on the contrary, the limited rainfall usually pene-

trates only to a relatively slight depth—a few feet—whence the water afterwards re-ascends, to be dissipated by evaporation. Thus the lime carbonate dissolved in its descent gradually accumulates within a very limited thickness of soil, and chiefly at the lowest point usually reached by the moisture. Concurrently, the diffused clay brought down by each rain stops at or near the same level; and both substances combine to form a mechanical union into a subsoil layer of "hardpan," the cement of which is lime carbonate, and which therefore effervesces (sizzes) to a greater or less degree when touched with a drop of acid.

These hardpan sheets are usually more or less discontinuous, the areas occupied by them being commonly of a rounded or oblong shape, and lowest in the middle. In case of unusually copious rains, or when irrigated, they may frequently be recognized by the formation of temporary ponds, deepest in the middle or axis of the sheet. Such stagnation of water serves ultimately, of course, to increase the hardness and thickness of the hardpan sheet, by the further dissolution of lime during the fermentation of vegetable matter that always occurs in stagnant water, and its subsequent deposition upon the concrete already formed.

Such hardpan areas are familiar to cultivators in the arid regions throughout the world; from the Rocky Mountains to the Pacific coast, as well as in northwest India, where the "kankar" is a formidable obstacle to the cultivation of lands otherwise very rich and capable of profuse production. In India it seems to assume, more frequently than in California and Arizona, the form of a hard crystalline, though very impure limestone, which no tool short of a crowbar can deal with. Of course roots cannot penetrate it, and after irrigation the water stands on the lands underlaid by it, drowning out what otherwise might have been a fair crop. The trouble is experienced somewhat in California, in some portions of the Great Valley, where soils of a fine silty character prevail; less often in the more coarsely sandy lands. In the heavy clay lands (*adobe*) of the lower grounds, such accumulations of lime carbonate are also quite common, as might be expected; but, contrary to expectation, they are usually less hard and offer less obstruction to roots and to the penetration of water than is the case in the silt soils. Moreover, the lime hardpan in these clay soils crumbles very rapidly upon exposure to the air, or thorough drainage, and is, therefore, less injurious, and less difficult to deal with than in other soils.

MAGNESIA CONTENTS OF SOILS IN THE ARID AND HUMID REGIONS.

While the differences in respect to the proportions of lime are the most prominent and decided, yet the related substance, magnesia, shows also a very marked and constant difference as between the soils of the humid and arid regions. It will be observed that the general

average for magnesia in the soils of the Atlantic slope is about double that of lime; Florida being the only state in which the average (of seven analyses) is lower for magnesia than for lime. In the arid region, on the contrary, magnesia on the general average is nearly the same as lime; in the average by states, slightly above it; thus bringing the ratio for the two regions for magnesia up to one to six or seven. This also is so decisive a showing that no accident could bring it about. We must conclude that climatic influences have dealt with magnesia similarly as with lime, which from the standpoint of the chemist is just what might be expected, since magnesia carbonate behaves very much like that of lime toward carbonated waters. It is not, however, known to exert any peculiar influence upon soils or plant nutrition; and hence, while its presence in the soils of the arid regions is corroborative of the evidence concerning lime, it is not of similar practical significance.

INFLUENCE OF CLIMATIC CONDITIONS UPON THE "INSOLUBLE RESIDUE."

Remembering, in discussing the facts shown by the table, that the fundamental difference between the régime of the humid and arid regions is the presence of an almost continuous leaching process, in which the carbonated water of the soil is the solvent; remembering, also, that the least soluble portion of rocks and soils is quartz or silica (sand, as usually understood), it would be predictable that this ingredient should in the humid region be found to be more abundant in soils than in the arid. This portion is represented by the "insoluble residue" of the table.

Inspection shows that both in the averages of the single states, and in both of the general averages, this difference between the soils of the humid and the arid regions of the United States is strongly pronounced; the ratio being substantially as 70 per cent. in the arid region to 84 per cent. in the humid.

We must then conclude that the leaching process must have influenced materially other soil ingredients than lime, which have remained behind in such amounts as to depress the percentage of insoluble residue in the soils. It remains to be shown what are the substances so retained.

SOLUBLE SILICA AND ALUMINA.

The ingredient most nearly correlated with the insoluble residue is the silica which remains behind with it when the acid with which the soil has been treated preparatory to analysis is evaporated to dryness. The gelatinous or pulverulent silica set free by the acid from the soil silicates being thus rendered insoluble in acid and water, it is separated from the really insoluble and undecomposed minerals by boiling with a strong solution of sodic carbonate, to which, after boiling, a

few drops of strong caustic soda lye have been added in order to prevent the re-precipitation of part of the soluble silica. The amount of the latter is obviously the measure of the extent to which the soil silicates have been decomposed in the treatment with acid.

The most prominent of these is usually supposed to be clay—the hydrous silicate of alumina that in its purest condition forms kaolinite or porcelain earth. Any alumina found in the usual course of soil analysis is generally referred to this mineral, which contains silica and alumina nearly in the proportion of 46 to 40.

In very many cases, however, the reference of these two ingredients to clay is manifestly unjustified. This is clearly so when (as not unfrequently happens) the amount of alumina found exceeds that which would form clay with the ascertained percentage of soluble silica; it is almost as certainly so when, in addition to the alumina, other bases (notably potash, lime, and magnesia) are found in proportions which preclude their being in combination with any other acidic compounds present. The only possible inference in such cases is that these bases, together with at least a portion of the alumina, are present in the form of hydros, and therefore easily decomposable silicates, or zeolites.

The subjoined analysis of a clay obtained in the usual process of mechanical soil analysis (by precipitating with common salt the turbid water remaining after 24 hours subsidence in a column of 200 millimeters) from a very generalized soil of northern Mississippi, shows one of the many cases in which the numerical ratios of the several ingredients are incompatible with the assumption that silica and alumina are present in combination as clay (kaolinite) only:

Insoluble matter	15.96
Soluble silica	33.10
Potash (K_2O)	1.47
Soda (Na_2O)	1.70
Lime (CaO).....	.09
Magnesia (MgO).....	1.33
Br. ox. of manganese (Mn_3O_4) .....	.30
Peroxide of iron (Fe_2O_3).....	18.76
Aluminia (Al_2O_3)	18.19
Phosphoric acid (P_2O_5) .....	.18
Sulphuric acid (SO_3).....	.06
Carbonic acid (CO_2).....	.00
Water and organic matter.....	9.00
Total	100.14

If in this case we assign all the alumina to silica, as required for the composition of kaolinite or true clay, there yet remains a trifle over twelve (12.17) per cent. of silica to be allotted to the other bases present. Deducting from this the ascertained amount of silica soluble in sodic carbonate, pre-existing in the raw material, (.38 per cent.) we come to 11.79 per cent. as the amount of silica which must have been

in combinations other than kaolinite, viz., hydrous silicates, or soil zeolites, formed either with the bases other than alumina shown in the analysis, or, more probably, perhaps containing some of the alumina itself in essential combination.

We are thus enabled to obtain from the determination of the soluble silica an estimate of the extent to which these soil zeolites, that form so important a portion of the soil in being the repositories of the reserve of more or less available mineral plant food, are present in the soils of the several regions. A glance at the table shows that the general average of soluble silica is very much greater in the soils of the arid regions than in those of the humid, approximating one to two in favor of the arid division.

But looking at the details of the several states, we find that on the arid side Washington has a relatively low figure for soluble silica, that in the average, however, is overborne by the high figures for California and Montana. The explanation of this fact probably lies in the derivation of the majority of the Washington soils examined, from lake deposits brought down gradually from the humid region at the heads of the Columbia drainage, where sandy beds are very prevalent; while the country rock—the basaltic eruptives—are very basic, and moreover slow to disintegrate. In California and Montana the rocks are infinitely varied, and the general outcome of their weathering is plainly a predominance of complex hydrous silicates in the soils, as compared with humid regions.

ZEOLITES ARE REPOSITORIES OF PLANT FOOD,

Nor should this be a matter of surprise when we consider the agencies which are brought to bear upon the soils of the arid regions with so much greater intensity than can be the case where the solutions resulting from the weathering process are continually removed as fast as formed, by the continuous leaching effect of atmospheric waters. In the soils of regions where summer rains are insignificant or wanting, these solutions not only remain, but are concentrated by evaporation to a point that, in the nature of the case, can never be reached in humid climates. Prominent among these soluble ingredients are the silicates and carbonates of the two alkalies, potash and soda. The former, when filtered through a soil containing the carbonates of lime and magnesia, will soon be transformed into complex silicates, in which potash takes precedence of soda, and which, existing in a very finely divided (at the outset in a gelatinous) condition, serve as an ever-ready reservoir to catch and store the lingering alkalies as they are set free from the rocks, whether in the form of soluble silicates or carbonates. The latter have another still important effect: in the concentrated form at least, they, themselves, are effective in decomposing silicate minerals refractory to milder agencies, such as calcic carbonate solutions; and thus the more de-

composed state in which we find the soil minerals of the arid regions is intelligible on that ground alone.

But it must not be forgotten that lime carbonate, though less effective than the corresponding alkali solutions, nevertheless is known to produce, by long continued action, chemical effects similar to those that are more quickly and energetically brought about by the action of caustic lime. In fact, the agricultural effects of "liming" are only in degree different from those produced by marling with finely pulverized carbonate; and in nature the same relation is strikingly exemplified in the peculiarly black humus that is characteristic of calcareous soils, but which can be much more quickly formed under the influence of caustic lime on peaty soils.

In the analysis of silicates we employ caustic lime for the setting-free of the alkalies and the formation of easily decomposable silicates, by igniting the mixture; but the carbonate will slowly produce a similar change, both in the laboratory and in the soils in which it is constantly present. This is strikingly seen when we contrast the analyses of calcareous clay soils of the humid region with the corresponding non-calcareous ones of the same. In the former the proportions of dissolved silica and alumina are almost invariably much greater than in the latter, so far as such comparisons are practicable without assured absolute identity of materials. That is, calcareous clays or clay soils are so sure to yield to the analyst large precipitates of alumina, that experience teaches him to employ smaller amounts for analysis than he would of non-calcareous materials, in order to avoid unmanageably large bulks of aluminic hydrate. It is but rarely that even the heaviest non-calcareous soils yield to the acid usually used in soil analysis more than 10 per cent. of alumina; while heavy calcareous clay (prairie) soils commonly yield between 13 and 20 per cent.* It would be interesting to verify this relation by artificial digestions of one and the same clays with calcic carbonate at high temperatures, as it must always be extremely difficult to insure absolute identity of all other conditions in the natural materials.

In most of these cases, what is true of alumina is also true of the soluble silica. But since the latter is constantly liable to be dissolved out by solutions of carbonated alkalies, it is not surprising that this relation is not always shown. What is shown in very many cases is that, since the amount of alumina dissolved greatly exceeds that of soluble silica, a portion of the latter must be present in a different form from that of clay (kaolinite); the only choice being between that of complex hydrous silicates (none of which, however, could contain as large a percentage of alumina as clay itself) and aluminic hydrate. The latter is alone capable of explaining the presence of more alumina than silica in easily soluble form; and the visible occurrence of

*Report of the Tenth Census, vols. 5 and 6; see especially the analyses of soils from Mississippi and Alabama. Also the Reports of the California Experiment Station.

"gibbsite" in modern formations renders this a perfectly simple and acceptable explanation. Since this mineral is known to be incapable of crystallization, we are, moreover, led to the presumption that it will, as a rule, be found in the finest portions of the soil, viz., in the "clay" of mechanical analysis. What part it may take in modifying the physical properties of the soil, we can thus far only conjecture; in two conspicuous cases of this kind, from Mississippi and California,* the soil material is characterized by such extraordinary tenacity and adhesiveness as to render tillage almost practically impossible, while the natural plant growth is very scanty. No corresponding extreme physical condition is, however, exhibited by the soils from Washington and Oregon of which analyses are given on page 14, in which an excess of alumina over soluble silica is likewise shown.

There is no very obvious reason, from the chemical standpoint, why iron, that is, ferric hydrate or iron rust, should be more abundant in the soils of the arid regions, as the averages given in the table suggest; moreover, the fact does not impress itself upon the eye, since the whitish or grayish tints are by far more common in the arid than in the humid regions of the United States at least. The California average is considerably influenced by the very highly ferruginous soils from the foothills of the Sierra Nevada; that of Oregon by the black, highly ferruginous country rock, from which they are partly derived. The average for Montana is not higher than that of three states of the humid region, and less than that of Kentucky. We might imagine a cause for depletion of iron in the soils of the humid areas in the frequency with which humid moisture and high temperature will during the summers concur toward the bringing about of a reducing process in the soil, which by getting the iron into proto-carbonate solution would make it liable to be leached into the subsoil, as is frequently the case; yet the resulting "black gravel" or bog ore, in its various forms, is of not unfrequent occurrence in the arid regions also. I therefore am not satisfied that a constant difference due to climatic conditions is shown by the data thus far at command.

An unexpected and apparently well-defined contrary relation appears to be shown as regards the related metal manganese; the average percentage of which is in all cases less in the arid than in the humid region, on the average over one to two. The cause of this relation is altogether obscure; it is too well maintained to be accidental. In any it is, so far as we know, of no consequence to vegetation.

As regards that highly important soil ingredient, phosphoric acid, the indication in the table that there is no characteristic difference in the average contents in soils of the arid and humid regions, respectively,

* These cases are Nos. 203 and 207, Mississippi (*Rep. Tenth Census*, vol. 5, p. 256), in which the soluble silica and alumina stand in the ratio of about seven to over twenty; and No. 703, California (*ibid.*, vol. 6, p. 712), in which the ratio is as nine to nearly sixteen. See also the table above, page 14.

is doubtless correct. This substance is so tenaciously retained by all soils that there is no conceivable reason why there should be any material influence exerted upon its quantity by leaching, or by any of the differences in the process of weathering that are known to exist between the two climatic regions. Moreover, it is obvious that the average for the arid region is made up out of very widely divergent data; that of California exceptionally low (lower than any of those for the humid regions), while those for Washington and Montana are exceptionally high. The latter is due to country rocks showing abundance of microscopic crystals of apatite, which in some cases raise the contents of the soils in phosphoric acid to nearly twice the average given for the states.

The forecast that for most California soils, fertilization with phosphates is of exceptional importance, has already been abundantly confirmed by experience.

The showing made by the table regarding sulphuric acid, that sulphates are less abundant in the soils of the arid than that of the humid region, is surprising in view of the prevalence of sulphates of the alkalies, which show themselves in the form of efflorescence but too frequently. It is true that the majority of such alkali soils have, on account of their exceptional and local nature (and usually heavy lime contents), been excluded from the comparison; otherwise the showing would have been quite the reverse. No significance attaches, therefore, to these figures.

POTASH AND SODA IN THE SOILS OF THE ARID AND HUMID REGIONS.

The compounds of the alkali metals, potassium and sodium, being on the whole much more soluble in water, even without the concurrence of carbonic acid, than those of calcium and magnesium, the leaching process that creates such pronounced differences in the case of the two earths must affect the alkali compounds very materially. Comparison of the soils of the two regions in this respect shows, indeed, very great differences in the average contents of potash and soda. For potash the ratio is .216 to .725 per cent. on the general average, and .187 to .825 per cent. in the average by states; for soda, .091 per cent. to .264 per cent. on the general average, and .071 per cent. to .251 per cent. in the average by states. For both, therefore, the general average ratio is as one to between three and four for the humid as against the arid region.

It is curious that an approximation to the ratio of one to three, or somewhat less, is maintained in the average proportion of soda to potash in both regions; but this does not by any means hold good in detail, very high potash percentages being often accompanied by figures for soda very much below the above ratio. This is the result of an important difference in the chemical behavior of the two alkalies,

which must be considered somewhat in detail in order to obtain a clear conception of the process by which alkali soils are formed.

The process of "kaolinization," being that by which clays are formed out of feldspathic minerals and rocks such as granite, diorite, trachyte, etc., results in the simultaneous formation of solutions of carbonates and silicates of potash and soda. These coming in contact with the corresponding compounds of lime and magnesia, also common products of rock decomposition, are partly taken up by the latter, forming complex, insoluble, hydrous silicates (zeolites). In these, however, potash whenever present takes precedence of soda; so that, when a solution of a potash compound is brought in contact with a zeolite containing much soda, the latter is partially or wholly displaced and, being soluble, tends to be washed away by the rainfall into the country drainage. Hence potash, fortunately for agriculture, is tenaciously held by soils, while soda accumulates only where the rainfall or drainage is insufficient to effect proper leaching, and in that case manifests itself in the formation of what is popularly known as alkali soils; namely, those in which a notable amount of soluble salts exist, and are kept in circulation by the alternation of rainfall and evaporation; the latter causing the salts to accumulate at the surface and to manifest themselves in the form of saline crusts or efflorescences.

The designation of alkali soils is, however, popularly bestowed somewhat indiscriminately upon two classes of lands of very different origin, and requiring for their reclamation quite different treatment. In both cases it is mainly the salts of the alkalies—potash and soda—that imbue the soil and tend to injure vegetation. But when we have to deal with seashore lands that owe their saline contents only to the more or less continuous flooding with salt or brackish water, the conditions differ materially from those prevailing in the case of the true alkali soils, which owe their contents of salts to the scantiness of the rainfall, as heretofore explained.

In the former case, that of saline lands, it is chiefly common salt (chloride of sodium) with some bittern (chlorides and sulphates of calcium and magnesium) that forms the soluble impregnation, which is, of course, practically independent of climatic conditions. In the latter, while common salt is also commonly present, the most abundant is usually Glauber's salt (sulphate of soda), and with it very frequently, as the least welcome ingredient, carbonate of soda (sal soda). According to chemical laws the presence of the latter substance excludes, practically, the earthy salts classed above as bittern.

The saline shore lands, being practically independent of climatic influences, lie outside of the limits of this paper.

Alkali lands are a characteristic feature of all regions of scanty rainfall, and are found on all the continents, in Europe, in a portion of the Hungarian lowlands, and in a few localities of Mediterranean Spain. It is true that occasionally we find in the humid regions limited areas

to which salts of various kinds are currently supplied from adjacent saline formations, as may be seen at some points in southern Mississippi and northern Louisiana. But such phenomena are entirely local and do not extend far from the source of supply, because the soluble salts are soon washed into the country drainage by the abundant rains.

In the arid regions, on the contrary, the substances composing the alkali salts are not only retained in their first soluble form, but by their continued presence influence profoundly the processes of soil formation in several ways.

In the accumulation of alkali salts of course much depends upon the nature of the soil ; for it is obvious that in very porous soils the leaching-out can occur much more readily than in those that permit of but very slow percolation, so that a rain may chiefly run off from the surface and cease before even an approach to a complete downward penetration can have occurred. It is therefore a well-known fact that alkali is most troublesome in the heavier (adobe) lands; and as these are apt, in addition, to coincide with the lower ground, toward which the soluble salts are naturally carried with the seepage, it is not uncommonly found impracticable to cultivate these extremely rich lands without special methods tending either to diminish the alkali itself, or at least to prevent its accumulation at the surface, where its most injurious effects are produced.

It need hardly be said that, special qualities of soil apart, the alkali salts decrease as hills or mountains are approached, where increased slopes, and usually pervious soils, combine to permit of their leaching-out with even a relatively scanty rainfall. And inasmuch as ordinarily the rainfall increases rapidly with elevation, everything concurs to prevent the accumulation of alkali in mountainous or even hilly regions. High-lying plains or plateaus, however, do not by any means necessarily share this exemption, as is well illustrated in the case of the great interior plateaus of America and Asia.

THE ALKALI LANDS OF THE ARID REGIONS.

CLIMATIC LIMITATIONS OF ALKALI LANDS.

CALIFORNIA.

The question concerning the amount of rainfall under which alkali salts can be retained by the soil to a noticeable and injurious extent, can best perhaps be investigated in California, where the eastern portion of the Great Valley constitutes a region of very regularly varied rainfall ; ranging from an annual mean of 34.60 inches at Redding on the north to (usually) less than 6 inches at Bakersfield on the south. The following table shows the decrease of rainfall to southward for a number of principal points in the valley :

Table of rainfall on the east side of the great valley of California.

Station.	Rainfall.	Station.	Rainfall.
	<i>Inches.</i>		<i>Inches.</i>
Redding	34.60	Lathrop	11.88
Red Bluff.....	23.79	Modesto.....	9.57
Chico.....	20.91	Merced.....	10.30
Nicolaus.....	18.55	Fresno	9.02
Sacramento	19.80	Tulare	7.00
Galt	16.72	Bakersfield.....	6.08
Stockton.....	13.18		

Apart from the decrease of rainfall to southward there is also a diminution from the eastern border of the valley toward the axis, and at some points even to the foot of the Coast Range on the western border. Thus Chico, on the east border, has nearly 21 inches; Orland, in the same latitude, but on the western edge of the valley, 16 inches. Marysville, on the east, 18.9; Colusa, in the axis, 16.24; Williams, on the west, 13.32 only. Tehama, only 10 miles south from Red Bluff, has not quite 16 inches against 23.79 at the former place. Of course, local conditions with respect to prevailing air currents have much to do with discrepancies, which, however, do not invalidate the general conclusions.

Roughly speaking, it may be said that the increase of alkali runs parallel with the decrease of rainfall in the valley; it is at its maximum near the south end, at its minimum near the north end, which, in fact, it does not reach. So far as its prevalence to an injurious extent is concerned, it practically ends, east of the Sacramento River, at or near the city of Sacramento, with an average rainfall of nearly 20 inches. Here the proximity to the base of the Sierra foothills exerts a disturbing influence, for we find at Marysville, forty miles farther to northward, but also farther out in the valley, only 18.9 inches. Local conditions prevent the accumulation of alkali salts east of the Sacramento River in this latitude; but immediately across, on the west side, all the heavier lands are alkaline, and with a rainfall of about 16 inches so continue, decreasingly, nearly to the head of the valley near Tehama.

To southward in the San Joaquin Valley, likewise, there is a general increase of alkali in the soil to westward, and in some regions clear to the foot of the coast range. The reason is, in part, the scanty drainage from that range, and the fact that the (tertiary) beds forming the immediate slopes are charged with both alkaline and earthy salts, and thus combine to increase the saline contents of the soils independently of climatic conditions; so that even the waters of many streams are in summer undrinkable. From similar causes limited alkali areas exist locally even near the coast, where the rainfall is in excess of 20 inches.

While, therefore, it can not be rigorously said that a certain rainfall conditions in all cases the alkalinity or non-alkalinity of soils, it cer-

tainly appears that in California, at least, 20 inches of rainfall is the upper limit beyond which the retention of any considerable amount of soluble salts in the soil becomes impossible under ordinary conditions of soil and drainage; while below that limit the degree of alkalinity is dependent more or less upon local conditions as well as soil texture, and may or may not reach the point at which these salts become of serious import to agriculture.

OREGON AND WASHINGTON.

If we extend the inquiry to other regions, notably to eastern Oregon and Washington on the north, where the climatic régime is similar to that of the "Franciscan" region of California, modified mainly by the greater cold of winter; we still find the same rule to hold good. There also the bulk of the rain or snow falls in the six months from November to April, inclusive, the rest of the year being practically rainless so far as any efficiency toward the leaching-out of soluble soil ingredients is concerned. This is especially true of the portions of these states lying between the Cascade Range on the west and the western branch of the Rocky Mountains (the Coeur d'Alene ranges) on the east, the Spokane River on the north, and the Blue Mountains on the south; excepting, of course, that portion which, on account of its proximity to the eastern chain, already enjoys a proportionally increased rainfall (to wit, the Palouse and Walla Walla country), and like northern California can produce annual crops without irrigation. Perhaps there is no part of the United States so severely afflicted with an excess of alkali salts near the surface as is the southern portion of what is known as the "Bend" country in Washington (Great Plain of the Columbia), with its lakes and streams of alkali water. Yet the northern half of the region is not only well suited to agriculture, but is actually rendered more so, in part, by the presence of a moderate amount of alkali salts. For the rainfall of this region we as yet have no data except the popular statement that it is awfully dry in the alkali region of the southern portion; while an increase toward the north must, apart from the successful cultivation, be inferred from the increase of timber as we approach the Spokane, and the fact that beyond that stream pine forest at once sets in. The precipitation at Fort Spokane, not far from the junction of the river with the Columbia, is, however, only about twelve inches; at Ellensburg, on the upper Yakima (west of the Columbia and farther to southward), nine inches; and, judging from the character of the vegetation, there is even less on the lower Yakima. Throughout this region alkaline efflorescences occur on most of the lower lands; while the rolling lands, owing to the pervious (silty) character of the soils, are generally free from any noticeable taint. Fort Simcoe, lying to southward at the northern foot of the partly wooded range which borders the Columbia River to northward of The Dalles, has over 13 inches, doubtless on ac-

count of that proximity; but to eastward the forest soon terminates and the range abuts on the Yakima plain, completely bare of tree growth and largely even of shrubs.

CENTRAL MONTANA.

With a rainfall ranging mostly between 7 and 14 inches, central Montana affords an interesting field of study in respect to the limitation of alkali by the amount of rainfall. Here the city of Helena occupies nearly the same relative position toward the Rocky Mountains as does Sacramento toward the Sierra Nevada, and the rainfall of the two cities is almost identical, being close to 20 inches. Owing to the location on a slope, no alkali appears within the city; but, as at Sacramento, it comes to the surface in the trough of the plain, to northward, and with decreasing rainfall becomes more and more conspicuous and troublesome as we descend the Missouri toward Fort Benton; the maximum being reached (together with the minimum of rainfall, so far as known—6.95 inches) in the region of about Fort Shaw, on Sun River, a western tributary of the Missouri. Here again, the perviousness of the silty soils makes the existence of alkali salts less apparent on the surface, but it becomes disagreeably obvious in the water of the springs, lakelets, and small streams of the region. East of the Missouri, the several groups and chains of mountains surrounding the Judith Basin modify the conditions of precipitation to a considerable, but not as yet accurately recorded, extent, leaving the northern part of the basin almost free from alkali land; but the southern portion, as well as the slopes toward the valley of the Musselshell River, are scarcely anywhere entirely free from the alkali taint. Toward the Yellowstone drainage area there is a gradual decrease of salts, and in the Yellowstone Valley itself alkali ceases to be a matter of practical interest.

These examples may suffice to show that while the presence of alkali is dependent upon a certain deficiency of rainfall, yet that fact alone does not necessarily imply its presence to any practically important extent, the greater or less perviousness of the soil and of the substrata, as well as a certain slope of the surface, being effectual in counteracting the accumulation. Nevertheless, as the table of soil composition shows, such deficiency remains potent everywhere in bringing about the main characteristics of the soils of the arid region, to wit., high percentages of lime, magnesia, and potash, and, relatively, of soda.

INDIA.

In India we find, in the Indo-Gangetic plain, a large area in which alkali (reh) is more or less troublesome to cultivation; extending all the way from the Indus and the Arabian Sea to a little beyond the Ganges, and from the Gulf of Cutch on the south to Afghanistan on the north, including all of Sind, Rajputana, the plains of the Punjab, the Northwest Provinces, and part of Oudh, to within a short distance of the

Himalaya ranges, incuding Lahore. Within this vast region the rainfall varies from a minimum of 4.3 inches at Jacobabad, on the Afghan frontier beyond the Indus, to over 30 at Cawnpore on the Ganges. We have but very scanty data as to the extent to which alkali salts prevail to an injurious extent within this area; all the provinces mentioned above are reported as suffering from "reh" more or less; but singularly enough the one region in which the evil has caused the appointment of a government commission to investigate its causes and remedies is the one, which, from the amount of rainfall, one would have supposed to be exempt from alkaline efflorescences. This is the country bordering upon the rivers Jumna and Ganges, and including the important cities of Delhi, Meerut, Agra, and Cawnpore. It is doubtless because of this fact, and of the high value of the land created by the extensive irrigation canals deriving their water from the two rivers, that the subject has here attracted such attention. The minimum rainfall occurs at Aligarh (24.3 inches), with 28.5 at Meerut and 27.6 at Delhi on the north, 26.5 at Agra and 26.7 at Etawah on the south. All these figures are materially above what in the arid region of North America appears to be the upper limit permitting of alkali efflorescences, viz., 20 inches or thereabouts; and the question as to the cause of this difference is of considerable interest, the more as no complaints of trouble with "reh" seem to come from the Deccan in southern India, where the same average rainfall of 24 to 30 inches prevails.

A study of the distribution of the rains through the year seems to account for the inefficacy of the rains in leaching the soil of the Northwest Provinces of its surplus salts. Unlike the "Franciscan" type of climate, in which nearly all the rainfall is concentrated within a consecutive period of six months, during which the soil is constantly kept wet enough to permit of percolation downward, the rains of northwest India fall more or less in all months of the year save November, but usually in such small amounts that no percolation is brought about, save that in the months of July and August nearly half of the annual precipitation comes down in torrential form, ill calculated to produce more than a wetting of the soil to a depth whence capillary rise will again carry the soluble salts to the surface. In the Deccan (south-central India) the distribution of the rains is less abrupt, keeping up more or less from March to December, inclusive, and with fewer torrential downpours. How little the latter can do towards removing the alkali salts is strikingly apparent even in Washington and Montana, where summer thunderstorms sometimes cause a sudden rise of the streams, quickly followed by dry stream beds. Such rains are as powerless to act upon the alkali in the soil as are the often repeated attempts to remove even the superficial efflorescences by quick and brief flooding. The first touch of the water dissolves the salts and the dry soil beneath instantly absorbs the solution, leaving the bulk of the water to flow by uselessly.

While to this extent the occurrence of alkali salts in India differs somewhat from that in North America, all the rest of the characteristics of the "reh-plague" are the same in both countries, and, so far as data are available, everywhere in the world. Unfortunately, the records even of the geological survey of India supply but scanty details in regard to the facts, although a good deal of discussion is had, from which we glean cursorily the main features of the case. The calcareous nature of the "reh" soils and their tendency to form hardpan or "kankar" which aggravates the evil, are referred to in connection with the leaching-out of the carbonate of lime from the higher slopes. The fact that the bottom water is frequently charged with salts, while deeper wells are free from any unusual taint, is mentioned in connection with the effects of irrigation; the undoubted fact that irrigation has increased the reh area is referred to, but the connection with the high-lying canals is called in question, because (as stated) no sensible dilution of the soil water has apparently taken place. Those who are familiar with the corresponding results of an exactly similar situation in California will hardly be disposed to concur in this doubt. As regards composition, also, the exact substances constantly found in our arid regions are mentioned; only considerably greater stress is laid upon the occurrence of nitrates, and nitrate of lime is mentioned as a possible good antidote for the carbonate of soda. It is not easy to see, from our point of view, how a sufficient amount of so expensive a salt should be procured for practical purposes, and why the cheap and abundant sulphate (gypsum) is not preferred in the recommendation.

ALKALI LAND OF OTHER COUNTRIES.

Turning to other countries of notably deficient rainfall from which data in point are available, we find in Egypt, Arabia, Syria, and Persia, as well as in the Aralo-Caspian plains, to the northern borders of Afghanistan, a state of things quite analogous to that of the arid regions of North America and India. Soils of extraordinary and lasting fertility when irrigated; a frequent mention of calcareous hardpan or tufa on the part of observant travelers; saline efflorescences as obstacles to cultivation; saline bottom waters, barely drinkable, in the shallow wells which alone the natives have found energy enough to dig; these are matters of constant mention, but too frequently attributed to the evaporation of the supposed salt-water basins. The climatic data available from these countries are mostly too scanty to determine what, in each of them, is the limit of rainfall beyond which alkaline salts cease to become apparent on the surface. It is interesting to note, in examining the records, how nearly the seasonal distribution and amount of rain credited to Jerusalem agrees with the "Franciscan" climate of central California; about 22 inches, falling from November to April, inclusive, enabling crops to grow without irri-

gation and preventing the accumulation of alkali salts to any injurious extent.

I am not aware that the subject of alkali lands, and the conditions of their existence and reclamation, have attracted the attention of the French colonies on the African coast quite as much as the manifest importance of the subject would seem to justify. The "shotts" on the northern edge of the desert seem to be regarded as hopeless alkali sinks only, from which to obtain soda for technical uses, as is also done in Fezzan.

Pretty much the same indifference appears even in Europe, in the Hungarian plain, where the gathering of "shekso" or crude soda, rather than cultivation, seems to be considered the destiny of the alkali lands.

COMPOSITION OF ALKALI SALTS IN DIFFERENT REGIONS.

In order to show the nature and possible functions of the alkali salts in soils I give below a table of analyses, selected from a large number, to show the great variety, as well as certain coincidences of composition, wherever found.

Composition of the soluble alkali in foreign localities.

Note.—To facilitate comparison, all the analytical data, given in the following tables have been recalculated so as to show the composition of the soluble portion of the efflorescences, exclusive of gypsum where present. In many cases potash, nitrates, and phosphates were doubtless present but were overlooked.

Europe.		Asia.		Africa.		Australia.	
		Plain of the Araxes.		Aden, "hurka,"*		Egypt, "trona," Fezzan, "trona," Bendigo, "alkali."†	
Compounds.	Hungarian Plain, "szekse,"	Kalosa.	Debrezzin.				
Potassium sulphate (K_2SO_4) .....	.2	1.6	10.4	15.5	.....	11.1	1.28
Sodium sulphate (Na_2SO_4)	48.1	92.5	14.7	69.0	7.0	38.3	1.63
Sodium carbonate (Na_2CO_3)	51.7	4.4	74.6	12.1	67.2	28.2	40.05
Sodium chloride ($NaCl$)	1.5	1.5	69.7	15.5	2.9	47.7	.....
Sodium phosphate (Na_3PO_4) .....	.....	.....	.....	32.8	48.2	14.0	81.88
Magnesium sulphate ($MgSO_4$) .....	.....	.....	.....	.....	.....	.....	.....
Magnesium chloride ($MgCl_2$) .....	.....	.....	.....	.....	.....	.....	.....
Total	100.00	100.00	99.7	100.00	100.00	100.00	100.00

* Also called "kara," i. e., "black alkali."

† Bulletin No. 14, Department of Agriculture, Victoria, page 18.

Composition of alkali in different states.

California.		Washington.											
Ingredients.		Tulare county.	Kern Co., Kern Is.	Los Angeles Co., Los Angeles Co.,	San Bernardino Co., San Bernardino Co.,	Orange Co., Orange Co., West.	Alameda County, Alameda Co.,	Yakima County, Yakima Co.,	Kittitas Co., Kittitas Co.,	Cherry Creek, Cherry Creek,	Spokane County, Spokane Co.,	Miles Southwest of Cottontown.	Miles Southwest of Sprague's.
Mixed Co ₃ , Mixed dead Bottom.	.....	10.33	2.52	6.76	1.76	1.34	.73	.05	3.93	.82	1.40	.96	.....
.....	43.86	48.97	27.60	38.39	39.99	39.64	.40	2.69	15.67	9.58	12.25	3.07	.....
.....	4.50	.....	.....	.....	.15	.....	42.07	41.57	41.64	45.59	43.03	51.29	.....
.....	1.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	4.80	1.12	2.91	1.05	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	5.52	24.78	6.43	13.20	51.23	19.82	.....	.....	.....	.....	.....	.....	.....
.....	2.19	.....	.....	.....	10.50	.....	.....	.....	.....	.....	.....	.....	.....
.....	6.81	17.92	13.20	16.69	11.62	.....	.....	.....	.....	.....	.....	.....	.....
.....	7.4	14.80	10.04	1.51	7.40	.....	.....	.....	.....	.....	.....	.....	.....
.....	17.15	.....	1.54	38.09	17.32	4.97	19.01	4.36	.....	4.41	7.93	4.99	3.86
.....	100.15	102.96	102.17	100.34	101.66	100.66	104.38	101.50	101.39	99.48	100.22	99.64	100.08
.....	.15	2.96	2.17	.34	1.66	.06	4.38	1.59	1.39	.07	.22	.17	.49
Total.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.41	100.00	99.47	99.59	.....

Composition of the soluble portion.

Compounds:														
K ₂ SO ₄	.....	.....	20.23	3.95	10.13	.92	5.31	20.62	3.90	.16	4.53	6.27	.....
Potassium carbonate (K ₂ CO ₃)	.....	.....	46.12	.....	25.28	88.42	43.34	66.78	18.44	15.17	15.90	.....	.....
Sodium sulphate (Na ₂ SO ₄)	.....	.....	.....	.....	19.73	.....	.....	.....	.....	.....	.....	.....	.....
Sodium nitrate (NaNO ₃)	.....	.....	34.38	65.72	32.58	.42	15.38	15.85	62.22	75.61	80.36	77.10	87.14
Sodium carbonate (Na ₂ CO ₃)	52.22	.....	17.45	3.98	14.75	.51	39.34	11.47	10.57	.52	1.76	1.34	4.03
Sodium chloride (NaCl)	33.00	1.46	2.05	8.42	2.25	1.02	.....	.....	.....	1.53	2.55	1.13	2.56
Sodium phosphate (Na ₂ HPO ₄)	4.94	1.78	.....	1.65	.....	.....	.....	.....	.....	.....	.....	.....	.....
Magnesium sulphate (MgSO ₄)	.....	.....	.....	.....	1.41	.....	.....	.....	.....	.....	.....	.....	.....
Ammmonium carbonate ((NH ₄) ₂ CO ₃)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Total.....	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.41	100.00	99.47	99.59	100.00	

Composition of alkali in different states—Continued.

Montana.		Nevada.	Wyoming.	Colorado.	Nebraska. [†]
Ingredients.	Megaher Co., Missoula Bottom, Centerville Ferry Lamding.	Lewis and Clarke county.	Chimrehill country.*	Sweetwater Valley, Rock Lake, Independe- nce, Marys Lake.	Near Denver, Alkali.
Bases and acids:					
Silica (SiO_2).....	.05	.50	.02	.03	1.50
Potash (K_2O).....	1.18	1.17	.87	4.12	1.53
Soda (Na_2O).....	39.56	33.53	33.53	18.61	41.61
Lime (CaO).....	2.86	1.91	1.91	.74	....
Magnesia (MgO).....	1.31	11.19	4.49	12.79	....
Peroxide of iron (Fe_2O_3) and alumina (Al_2O_3) .....	....	.12	.08	....	....
Phosphoric acid (P_2O_5).....	34.97	38.78	53.84	.06	....
Sulphuric acid (SO_3).....	5.37	....	53.48	41.34	....
Nitric acid (N_2O_5).....	1.19	2.56	.65	.26	5.38
Carbonic acid (CO_2).....	15.40	6.29	.59	.10	3.45
Chlorine (Cl).....	1.29	19.72	4.39	9.59	5.78
Organic matter and water of crystallization .....	....	....	....	....	....
Less excess O due to chlorine	103.18	101.14	100.18	99.69	100.59
	3.48	1.42	.11	.02	.80
Total.....	99.70	99.72	100.07	99.67	99.79

Composition of the soluble portion.

* Hayden's Report, 1871.

† Hayden, 1873.

It will be seen that all over the world the saline efflorescences, occurring over wide areas and owing their existence to general causes, have, as their prominent ingredients, the three sodium salts—chloride (common salt), sulphate (Glauber's salt), and carbonate (sal-soda). The relative proportions of these vary greatly, especially as regards the chloride and carbonate; the sulphate is on the whole the one almost invariably present in considerable proportion. In addition to these we find, usually in relatively small proportions, what might be called accessory ingredients, depending more or less upon local conditions, climatic as well as geological, but frequently of very great practical importance. Among these, the salts of potassium (potash), the nitrates, and the phosphates are of particular interest to agriculture, since they represent the three elements usually supplied in fertilizers; whence it follows that their presence in the soluble form in such proportions as to participate in the formation of alkali crusts on the surface is of no mean interest to the farmer, since it argues the occurrence of an excess of plant food in the soil, and, therefore, the needlessness of fertilization while this state of things continues.

It is, therefore, of special interest to determine to what extent the presence or absence of these accessories is dependent upon climatic conditions, and what local conditions may modify the result.

Nitrates.—Of the accessory ingredients, those most manifestly dependent upon climatic conditions are the nitrates. It is well known that the process upon which their formation depends is materially conditioned upon a certain high temperature (about 75° F.); a moderate degree of moisture, permitting the easy access of air and forbidding the existence of reductive fermentations; the presence of calcic or magnesic carbonate; and, most of all, upon that of the “nitrifying organism,” without which the other conditions are powerless to act. Anything that paralyzes or destroys that organism is fatal to nitrification.

Among the ingredients that might be considered as certainly injurious to the life of the organisms in question are the chlorides of calcium and magnesium (bittern) and the carbonate of soda (and potash) when present in any large proportion, *e. g.*, so as to dissolve the humus of the soil, forming what is familiarly known as black alkali. We should therefore expect to find nitrates scarce or absent where large percentages of carbonate of soda are found in the alkaline salts and relatively abundant when sulphate and chloride are chiefly present. Actual examination fully confirms this *a priori* conclusion. The occurrence of nitrates in large proportion is confined to those regions in which white alkali is predominant—that is, neutral salts whose presence does not injure the activity of the nitrifying organism. This is confirmed also by the fact that the nitre beds of South America, as well as those of Nevada (White Plains), contain the saltpeter asso-

ciated only with the two neutral salts—sulphate and chloride of sodium. The same rule will be observed to hold good in the cases in which nitrates are found in notable amounts in the alkali salts from Montana and California, of which analyses are given above. No nitrates are found in the highly carbonated salts of Washington.

We have thus in the necessarily calcareous nature of the soils of the arid region the fulfillment of one necessary condition of ready nitrification. In the moderate moisture condition of the soils of the same region a favoring condition, so far as oxidation is concerned, together with the substitution of eremacausis (slow combustion) of the soil humus in the place of the fermentations that under humid conditions frequently not only arrest all oxidation, but also, by the formation of poisonous compounds (ferrous and manganous salts), actually destroy the life of the nitrifying organism. Even the exceptional condition of a strong impregnation with carbonates of the alkalies does not act as unfavorably upon plant nutrition as might be inferred, for it is apparent from the analytical record as well as from the evidence of the senses that in that case the evolution of ammonia from the humus can serve as a source of direct supply to vegetation, and, finally, whatever nitrates are formed are not, as in humid climates, liable to be leached currently from the soil beyond the reach of plants, but remain year after year in actual accumulation. We are thus justified in the conclusion that aridity is peculiarly favorable to the supplying of nitrogen to plants.

Potash.—While the presence of this substance is to some extent dependent upon the character of the country rock, being often very high where (true) granites contribute largely to the soils, yet its accumulation in the soils themselves seems to follow, as a matter of course, along with and in preference to the sodium salts, the cause of the difference being its more tenacious retention by the soil. As regards the water-soluble salts, it is probable that where no potash appears in the analysis of an alkali salt it has simply been overlooked or neglected. It will be noted that in California and Montana potash salts frequently constitute from 7 to 10 per cent. of the whole mass of alkali, forming a supply that, when calculated to the soil mass to the depth to which the roots of crops are likely to reach, promises to defer indefinitely the need of supplying potash fertilizers to such soils. There does not appear to be any relation between the amounts of potash present and the neutral or carbonated condition of the salts.

Phosphoric acid or phosphates.—The slight solubility of earthy phosphates of necessity relegates the abundant occurrence of soluble phosphates to the cases where the salts are highly carbonated, it is therefore chiefly in the very black alkali that we find notable amounts of dissolved (sodic) phosphate. But in some cases these amounts are sufficient to promise the farmer, as in the case of potash salts and nitrates, a long exemption from the purchase of phosphate fertilizers.

In view of these facts, it seems abundantly worth while to examine carefully the conditions under which the two types of alkali salts—the neutral or white, and the alkaline, carbonated, or black—respectively occur, and to what extent we may be able to control their injurious effects upon vegetation.

FORMATION OF NATURAL DEPOSITS OF CARBONATE OF SODA.

It is curious to search in the past and even current literature on the general subject for a reasonable explanation of the occurrence of carbonate of soda in nature. There seems to be a consensus of opinion that the carbonation of the soda is connected in some way with the presence of limestone or the carbonate of lime, and that an exchange has occurred in which either common salt or Glauber's salt have transferred their acidic components to lime and have become carbonates instead. But how such an exchange is to be effected, in view of the exactly opposite reaction that occurs when alkali carbonates and earth sulphates or chlorides are brought in contact in our laboratories, has led to many wild conjectures without a tangible basis.

Yet the simple explanation of the contrary reaction was given and published as early as 1826 by Schweigger; in 1859 it was again observed by Alex. Müller, in a different form; but neither these chemists, nor any of their readers, appear to have perceived the important bearing of this reaction, not only upon the formation of the natural deposits of carbonate of soda, but also upon a multitude of processes in chemical geology.

Without going into detail, which has been published elsewhere,* it may be broadly stated that the formation of carbonated alkalies occurs whenever the neutral alkaline salts (chlorides or sulphates) are placed in presence of lime or magnesia carbonates *and* carbonic acid, or of alkali "super-carbonates" (hydro-carbonates) containing even a slight excess of carbonic acid above the normal carbonate; the latter being the actual condition of all natural sodas. In that case, crystals of gypsum may be seen, *e. g.*, in the residue from the evaporation of a mineral water which nevertheless shows a strong alkaline reaction; and such alkaline reaction is also obtained when carbonic acid is passed into a solution of common salt in which calcic carbonate is kept suspended, the formation of calcic chloride being simultaneous with that of the alkali hydro-carbonate.

It is easy to see that these conditions are constantly being fulfilled in nature; for the decay and fermentation of vegetable matter is constantly progressing in soils, swamps, and lakes, and as evaporation progresses the alkaline carbonate crystallizes out on the surface, or margins, while gypsum or calcium chloride accumulates on the bottom, or in the waters.

* Proceedings of the American Association for the Promotion of Agricultural Science, for 1888 and 1890.

It has been shown above that the soils of arid regions are almost necessarily calcareous, free carbonate of lime being present; as are also the salts of the alkalies. The conditions for the formation of carbonates of the alkalies just recited are, therefore, fulfilled wherever enough of vegetable decay (or evolution of carbonic gas from other causes) goes on so as to impart even a slight excess of carbonic acid to the soil or other water; and thus black alkali is formed, to an extent depending upon the excess of carbonic acid available for the process. It is evident that this excess will be greater in moist, close soils, rich in humus, than in loose and pervious ones; and thus the fact that black alkali is mainly found in low ground, and in rather close soils, finds a ready explanation.

WARM CLIMATES FAVOR THE FORMATION OF SODA CARBONATES.

But since vegetable decay is essentially dependent upon a certain elevation of temperature, and is totally suppressed by a certain degree of cold, it follows that, other things being equal, the formation of the alkaline carbonates will be most abundant in warm climates. The record of the occurrence of the soda deposits that in time past were of such industrial importance as the only sources of sodic carbonate, answers fully the requirements of this condition. Egypt, the African arid region generally, Mexico, the Aralo-Caspian lowlands, Turkestan, and the arid regions of western India, are the well-known sources from which the supplies of the mineral alkali (Trona, Urao) were formerly obtained. Were not the reaction limited to relatively dilute solutions,* its cheapness would soon drive all other processes of soda manufacture out of existence.

We do not, therefore, ordinarily expect to find alkaline carbonates abundant in the colder portions of the arid region; and this, as the table shows, is pointedly true as regards Montana. But in Washington, practically in the same latitude, the showing is quite different; we find here not only the carbonate of soda predominant, but it is present in percentages as high as those which, in Montana and California, are shown by the Glauber's salt.

But examination also shows, in the case of Washington, a special cause of this state of things. Almost the entire area on which alkali occurs in that state is covered by the black eruptive rocks, commonly, although to a great extent improperly, called basalts. As eruptives, these rocks are, of course, entirely free from gypsum, and but very rarely show even a trace of sulphurets. There is, therefore, no source from which sulphates could derive their essential ingredient; and thus the sodic carbonate, originally formed in the decomposition of the basalt by the atmospheric agencies, simply continues unchanged, as it emerges with the spring waters from the crevices of the rocks. Yet, in a few cases, where the basaltic eruptives are overlaid by a

*The limit is reached at about .4 per cent.

somewhat considerable mass of stratified (cretaceous and tertiary) deposits, the sodic carbonate is in the minority, and, as in Montana, the sulphate predominates.

That such local accidents as these should bring about apparent contradictions is to be expected; yet, even in this case, they prove the rule.

RECLAMATION OF ALKALI LANDS.

While the details of the subject of reclaiming alkali lands, that is, freeing them from the injurious effects of the excess of salts so as to render them available for profitable culture, do not lie within the proper limits of this paper, yet the importance of the subject and its direct connection with climatic conditions render it desirable that it should be discussed at least in outline.

EFFECTS OF IRRIGATION UPON ALKALI SOILS.

Since, as has been elaborately discussed above, the occurrence of soluble salts in soils is directly due to deficient rainfall and consequent failure to leach out the soluble matters, the direct inference might be that when irrigation makes up this deficiency to the extent required by success in cultivation, the normal leaching process would be established, and trouble from that source would cease. So far from this, it is found in practice that irrigation greatly increases the accumulation of alkali at or near the surface, often to such an extent as (in the case of black alkali) to render cultivation impossible or at least unprofitable.

The reason of this apparent discrepancy is simply that the amount as well as the distribution of the irrigation water is different from that of the rainfall of the humid regions. Usually the amount of irrigation water used is less than the annual rainfall of humid climates; and besides, it is used in great abundance for a short time, the object being to wet the soil just to the necessary depth and no more. The water thus used carries the alkali with it; but as it does not reach the country drainage, when evaporation begins it re-ascends and, finally, if the whole of the water evaporates, the whole of the alkali comes to, or close to, the surface. Now as irrigation in the arid regions usually penetrates deeper than the rains, this implies that a larger amount of alkali is now carried to the surface than was the case before. If, worse than this, a pervious soil and leaky irrigation ditches gradually fill up the whole country with water from below, the entire amount of alkali salts previously existing in the dry soil mass, perhaps to depths of forty or fifty feet, is brought near the surface, and thus the bottom water becomes the source of an almost inexhaustible supply of alkali, which may render the further cultivation of the lands impossible unless done away with.

UNDERDRAINAGE THE UNIVERSAL REMEDY.

It is obvious that all these difficulties could be remedied by under-

drainage; for it would be perfectly easy to wash out of the soils above such drains every trace of alkali by one somewhat prolonged flooding; and as the bottom water would likewise be held in check by the same drains, no further supply would rise from below even in case of an ascent of the irrigation water by "filling up." Underdrainage is, therefore, a complete and full remedy for alkali lands.

But underdrainage is expensive; moreover, as we have seen, the alkali salts themselves are far from being throughout injurious, but do in fact almost always contain highly valuable soil ingredients in the most available form. To leach these out means a heavy loss of plant food, which would sooner or later have to be made up by the purchase of fertilizers.

REMEDIES OTHER THAN UNDERDRAINAGE.

If, then, there are other less radical remedies that can be applied by the farmer, their use is to be preferred on that ground alone. These possible remedies will be briefly stated:

1. Since the soil water is very rarely so strongly tainted with alkali salts as to injure the roots directly, but becomes harmful mainly when accumulated at or near the surface to such an extent as to corrode the root crown, the obvious remedy consists in preventing such accumulation by checking evaporation. Deep and thorough tillage persistently maintained throughout the season is alone, in a large number of cases, all that is necessary for perfectly successful cultivation of light alkali lands; provided always that the alkali be in the main white, that is, consists of the sulphate and chloride of sodium, and does not contain any large proportion of carbonate of soda.

Occupation of the land by a crop that fully shades the soil and restricts evaporation to that which goes on through the leaves of the plants, also permits of profitable use of alkali soils. Such crops are, for instance, alfalfa, ramie, clovers, etc. The main difficulty is usually to secure a stand of such crops, because of the injurious effects of the salts on germination. The same difficulty is experienced in rooting cuttings, but the planting of rooted stock usually succeeds with good tillage.

2. If, however, the alkali be of the black kind, strong enough to dissolve wholly or partially the humus of the soil, the first thing needful is the neutralization of the carbonate, which, when raised to the surface, not only exerts a powerfully corrosive action upon the root crowns and stems of plants, but kills all small seeds and thus prevents the obtaining of a stand. But its injurious action does not end there; in even moderately clayey soils it renders tillage almost impossible by destroying the tilth or "flocculation" of the clay, and converting the soil into a mass more suitable for the potter's lathe than for tillage. Moreover, it dissolves that important soil constituent, humus or vegetable mold, and, as has been stated already, by impairing or destroy-

ing the vitality of the nitrifying organism it also prevents one of the most essential processes in the soil, conducive to plant nutrition.

GYPSUM NEUTRALIZES BLACK ALKALI.

The neutralization or transformation required is easily and cheaply accomplished by the use of gypsum or land plaster, which, under normal conditions of culture, exchanges its acidic constituent with the sodic carbonate, resulting in the formation of carbonate of lime and sulphate of soda, or Glauber's salt, in other words, white alkali.

The contrary reaction, by which limestone and Glauber's salt may form carbonate of soda and gypsum, can only occur under conditions incompatible with good cultivation, and practically, as experience shows, does not occur to a sufficient extent to vitiate the practical success of the gypsum treatment of black alkali lands.

3. But the usefulness of the gypsum does not end there. While correcting the physical (tillage) conditions of the soil and preventing any damage by corrosion, it also renders insoluble the humus taken up and dissolved by the carbonate of soda, giving it back to the soil. Moreover, when soluble phosphates are present, this precious soil ingredient is also withdrawn from solution and is retained in the soil in a most effective form.

Whether or not gypsum also tends to render potash held in solution less soluble by the formation of complex silicates is a point not yet determined. It of course does not and cannot prevent the waste by leaching out of the important and costly nitrates through any chemical action. But as, practically, the use of gypsum in sufficient amounts renders unnecessary, probably in three out of four cases, the resort to the costly ultimate remedy, underdrainage, and enables the farmer to deal with the alkali by merely maintaining very thorough cultivation, it does to that extent subserve an important use in respect to the saving of nitrates also.

So far, then, as the dreaded alkali salts are concerned, it is perfectly feasible, in the vast majority of cases, to conquer them by the judicious use of these remedies, retaining in the soil a wealth of plant food which in humid climates would have passed into the streams and the sea.

4. *Calcareous hardpan*.—As to the frequent occurrence of calcareous hardpan—the kankar of the “usar-lands” of India—it adds a difficulty in preventing the penetration of roots as well as of water; and when leaky irrigation ditches in pervious soils cause the bottom water to rise from below, the saline solution that forms the upper layer of that water (as the result of upward leaching of the whole soil) flows in over the edges of the basin-shaped hardpan areas, and of course remains and evaporates there, causing a local and exceedingly rapid increase of the alkaline impregnation, sometimes resulting in the formation of small alkali ponds.

The breaking-up of this hardpan layer is the most important thing to be done; but as it rarely lies shallow enough to be reached even by the deepest plowing, it has been found best to reserve such lands for the planting of fruit trees, or vines, and before doing so to break up the hardpan around the spots, where the holes are made either with crowbars or (in America at least more cheaply) by small charges of moderately strong dynamite, which so shatter and crack the hardpan that not only can roots penetrate to a sufficient extent, but the drainage thus induced seems often to gradually so soften and crumble the mass that it practically disappears as an obstacle to cultivation.

In cases where the existence of hardpan had not been observed until the trees planted began to languish on account of the inability of their roots to penetrate to sufficient depth, the use of dynamite cartridges on opposite sides of the young trees has produced the necessary relief without injury to the trees.

Clayey hardpan.—On the other hand, the compacted, puddled, clayey layers that sometimes takes the place of the calcareous hardpan in bad cases of black or carbonate alkali, and are equally injurious, yield gradually to the effects of the neutralization of the carbonates by gypsum, which destroys the puddled condition of the clay brought about by the carbonated alkali and thus enables roots to penetrate, and water to drain through these layers. This effect of gypsum may be seen strikingly on pieces of such clayey crust that have been brought to the surface and treated with gypsum, which within a few days causes them to crumble, and assume the normal condition of soil.

CONCLUDING REMARKS.

In the summary review of the relation of climate to soils—the two factors which essentially control the production of the necessities of life—that forms the subject of this paper, the scantiness and incompleteness of the data thus far available on a topic as interesting theoretically, as practically important, is painfully apparent; and to no one more so than to the writer himself, who has made soil studies a favorite pursuit during most of his active life. While the intrinsic difficulties to be met in such an investigation are sufficiently great, the remarkable looseness of observations bearing upon it, their usually sporadic and unsystematic nature, and the fact that they are so thinly scattered in various kinds of literature—travels, geography, statistics, reports on geological, meteorological, topographical, and even botanical topics, together with encyclopedias and miscellaneous technical works of reference, renders their collation and elaboration very laborious and thus far rather unsatisfactory. It should not, therefore, be surprising to anyone if in this first attempt at a systematic exposition of the subject there are many important gaps and omissions that might have been avoided had a more complete library and a larger share of leisure been at command.

It may be hoped, however, that this paper may serve at least the purpose of enlisting in the study of this, the latest phase of chemical geology, a larger number of active workers and observers, so that at least the large amount of information actually existing may be gathered together and made practically useful; thus leading the way to a better understanding of the character, capabilities, and needs of the lands of the various regions, and of the means of utilizing them to the best advantage. The eminently practical nature of such investigations should commend them to greater attention from public geological surveys, in which a vast amount of labor is devoted to subjects of very much less interest and importance, whether theoretical or practical. The apathy that has prevailed, in regard to these studies, would be difficult to understand but for two considerations, one historical, the other intrinsic. From the latter point of view, the undeniable difficulty and complexity of the subject of soil study, and the want of immediately brilliant and remunerative results to the worker, is no mean deterrent factor. Historically, direct soil investigation received a set-back in the early part of this century, when upon extravagant expectations from its application to agriculture there followed a reaction which has not even yet subsided entirely. But it certainly is high time that such prejudices should give way to a reasonable reconsideration of the facts from a modern scientific standpoint; and that in the prosecution of public surveys, the interests of agriculture should cease to be the stepchild of which the name is used only for the sake of conciliating the favor of the large class dependent upon its intelligent prosecution. Conjointly with the study of soils, that of climatic conditions is of the utmost practical and theoretical importance; and ample means for the prosecution of both branches of study should be provided. The Experiment Stations of the United States, as now constituted, have not the means for a sufficiently rapid and energetic prosecution of either, to respond to the demands made upon them. Meteorological stations must be made more numerous, and should largely be located with reference to the agricultural problems to be determined in connection with them. Actual field surveys to define the agricultural subdivisions and to study their peculiarities should be made by parties covering ably not only the agricultural, but also the meteorological, geological, and botanical aspects of the several problems. This will be but simple and tardy justice to the fundamental industry upon which the very existence of nations depends.



